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Sherman Hoyt

A

FIRST BOOK IN GEOLOGY.

DESIGNED FOR

THE USE OF BEGINNERS.

BY

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INTRODUCTION.

THIS First Book of Geology is intended to give the beginner in the study of that science some general ideas concerning the action of those forces that have shaped the earth. Only a very small part of the more important facts that constitute the store of the geologist is given within its pages. The effort of the writer has been to select from that ample store such topics as will give the student an idea of the world as a great workshop, where the geological forces are constantly working towards definite ends.

The greatest and most easily seen of these agents is water, therefore the book begins with a study of water in its most simple mode of action. Next, the action of heat, in its various ways of working, should command the student's attention. Finally, the animal and vegetable life of the earth, whose forces come mainly from the action of heat, receive some attention.

It will be well for the student to have a general idea of the solar system, for all this machinery of the earth's workshop depends in a large measure on the way in which

the sun acts on the earth. The sun is related to the earth as the boiler to the steam engine, and it is well to know something of its nature, and of the motions of the earth about it, before looking at its effects. Although this preliminary knowledge is desirable, it is not indispensabie, for the text explains itself.

However carefully a text-book may be prepared, and however well it may be used, it cannot of itself alone give much insight into nature. This must come from the use of the student's eyes and mind. The most the student can expect from the book is an idea of what is to be seen in the outer world. He will not really know much of this world until he has learned to read the facts himself. The real use of the book to the beginner is to show those things that cannot be readily seen, and to set forth the nature of the forces that act in propelling the earth's machinery.

It will be noticed that some of the most important points in the mechanism of the earth are repeatedly re ferred to in successive chapters. This has been done with a view to fixing the memory of the most important truths by looking at them from many sides. Every one who has taught geology must have seen the importance of considering each important fact from many points of view.

In using this book, the student should, under each chap-

ter, seek to find if there are not some facts in his neighborhood that have a bearing on the matter given in the text. Some of the chapters give an account of matters which are found only in a few parts of the earth. Rarely will a student find himself in a position to see with his own eyes the structure or action of volcanoes, or the way in which caverns are formed, but there will always be some part of the book where he can help his understanding of the matter with his own eyes.

Let me also urge upon the students who use this little first book that they help themselves to a more pleasant relation with their world by making collections of minerals, fossils, plants, and other objects that will tell them something of nature. Not only is there to most young people a peculiar charm in owning a collection of this sort, but, if the owner will learn all he can about each object in his collection, he will soon come to have a valuable fund of precise and well-remembered information that will stay by him all his life; while the things that have had nothing but words to fix them on the memory will soon fade away.

But, above all, I beg each reader and student of this book to remember that this earth is full of lessons that can be read by every one who wishes to know them,— lessons that will widen the mind and make the soul more

fit for the duties and pleasures of life. The inattentive eye never gets this teaching; but, to those who learn to look rightly on this world, it gives without stint from its great store of truth.

The woodcuts in this book were drawn on wood by Mr. Charles E. Robinson. They are mostly original, but I am indebted to the works of Professor J. D. Dana, Joseph Leidy, and H. A. Nicholson, and to the *Seaside Studies in Natural History* of Mrs. E. C. Agassiz, and Alexander Agassiz, for certain figures.

N. S. SHALER.

CAMBRIDGE, MASS., Jan. 1, 1884.

QUESTIONS FOR THE USE OF STUDENTS.

It should be noticed that sometimes these questions are designed to direct the student to his personal experiences as well as to the statements of the book. A few questions are enclosed in brackets. These may be omitted, as they are a little outside of the text.

CHAPTER I.

Lesson I. Page 1.

1. What variety do we notice in river pebbles? 2. What is the history of these river pebbles? 3. In what way do they journey down stream? 4. Compare the making of boys' marbles with the making of pebbles. 5. How does frost help in the work? 6. How can this be shown by means of a bomb shell?

Lesson II. Page 5.

1. What is a beach? 2. How does the sea-beach wear its pebbles? 3. What is formed of the ground-up pebbles? 4. Is the same grinding up carried on in a river? 5. How do the two processes differ? 6. Whereabouts on the beach are the pebbles the largest? 7. How does the sea begin the process of pebble making?

Lesson III. Page 8.

1. What is a glacier? 2. How do its pebbles differ from those made in rivers and on beaches? 3. What are moraines? 4. How are glacial pebbles made? 5. Finding these pebbles where no glaciers now exist, what do they teach us? 6. Where are glacial pebbles found in North America? 7. If you live in the part of North Amer-

ica where glaciers have been, you will find gravel heaps on the hill-sides and tops, and the newly uncovered bed rocks will be scratched or smoothed. Is this the case in the region where you live?

Lesson IV. Page 12.

1. How do sand grains differ from pebbles? 2. Describe the appearance of sand. 3. What do we obtain if we melt sand? 4. When and how is sand made? 5. How does sand help the streams to wear the rocks? 6. How does the sandblast act in carving glass?

Lesson V. Page 15.

1. Where do we see the action of sand the best? 2. Why do not the waves wear sand beaches very much? 3. Under what circumstances does the sand get ground up on the beach? 4. How does the sand escape from the waves into the air? 5. What are dunes? 6. Why are they more common in Europe than in America? 7. Where are they very large? 8. What is the effect of making a hole in the dunes? 9. How does the sand travel out to sea? 10. Where is the most sand made? 11. Why are there dunes on the Sahara? 12. Is sand formed beneath glaciers? 13. What is the effect of blown sand on the rocks it passes over?

Lesson VI. Page 20.

1. Of what is mud composed? 2. How is it made? 3. How does it change in nature as we go down stream? 4. Is it formed on seashores? 5. How is mud made in soils? 6. What is the action of earthworms? 7. Of plant roots? 8. Describe the several actions that make mud.

Lesson VII. Page 24.

1. On what does all the life of the land depend? 2. Describe a soil. 3. Have you ever noticed how a soil is made? 4. From what things are soils made? 5. How do soils form on bare rock? 6. On what does the richness of a soil depend? 7. Describe the action of tillage on soils. 8. How are soils formed along rivers? 9. How do glacial soils differ from others? 10. Why do we owe a duty by soils?

CHAPTER II.

Lesson I. Page 30.

1. When pebbles are connected together, what is the rock called? 2. What is the millstone grit? 3. How are the stones bound together? 4. How are great quantities of pebbles brought together? 5. What do we learn from the process of making brick? 6. How can the rocks be made very hot? 7. What changes of shape sometimes occur in the pebbles of pudding-stones? 8. Why do small pebbles last a long time?

Lesson II. Page 34.

1. Of what are sandstones made? 2. Describe the bedding of sandstones. 3. How is cross-bedding made? 4. Why are sandstones found over so large a part of the world?

Lesson III. Page 36.

1. Why are the clay or mud stones found over a wider field than the other rocks? 2. How do volcanoes help the making of mud on the sea-floor? 3. What is pumice? 4. Why can it float very far? 5. What is the difference in the rate of making of claystones and sandstones? [6. Does this teach us any important fact?]

Lesson IV. Page 38.

1. How do limestones differ from rocks previously described? 2. How are they formed? 3. What are coral reefs? 4. Where do coral reefs abound? 5. Account for their shapes. 6. Why is a motion of the water necessary? 7. Are coral reefs the most powerful makers of limestone? 8. What can you say of foraminifera? 9. What changes have been brought about in certain limestones by the action of heat? 10. What effect have these changes on the animal remains buried in the limestone? 11. How is lime supplied to the sea to replace that which is constantly being taken from it by animals? 12. How do limestones affect soils? 13. Describe the course of matter from land to sea and from sea back to land. [14. What is the force that brings about this movement?]

Lesson V. Page 46.

1. Of what does coal consist? 2. Name the principal varieties of coaly matter. 3. How do plants obtain carbon? 4. What happens

when leaves, branches, or trunks of trees fall to the ground? 5. How, in some cases, is the wood preserved from complete decay? 6. Compare the process of decay in a wet and in a dry forest. 7. What is peat? 8. How can peat bogs be converted into coal? 9. How has coal been artificially made? 10. How can anthracite coal be produced from bituminous coal? 11. What do we see on the coal field near Richmond, Va.? 12. What was the climate during the carboniferous period? 13. Whence comes the heat that we find in coal? 14. How long has coal been in use? 15. Where are the largest coal fields? 16. How is petroleum formed? 17. Where has it long been gathered? 18. Where is the greatest amount found? 19. What other form of burnable matter is found in the earth? [20. How does coal affect the prosperity of nations?]

CHAPTER III.

Lesson I. Page 56.

1. Compare air and ocean. 2. What is the principal gas of the atmosphere? 3. Of what sort of bits is the air believed to be composed? 4. How do we know that the air can easily move? 5. How do we know that it can take up particles of water? 6. How do we know that cold makes it heavier? 7. What is the effect of the sun on the air at the equator? 8. What is the effect of the lands on the winds? 9. What would be the behavior of winds if the earth were all land or all water? 10. Describe currents of water through air to lands, thence back to seas. 11. What is one important effect? 12. How does the air act as a blanket? 13. In what other way does air help life? [14. How do we know that the spaces of the heavens are very cold?]

Lesson II. Page 62.

1. Compare atmosphere and oceans. 2. Describe work of water dependent on its dissolving power. 3. How does water work as a means of carriage of matter? 4. How does it carry heat? 5. What would be the effect if the Gulf Stream ceased to move?

Lesson III. Page 66.

1. What are veins? 2. How are the crevices formed? 3. How are they filled? 4. What valuable substances are found in them? 5. Describe some like deposits not in vein crevices. 6. Describe the way in

which metals from veins may pass to the sea. 7. How may the metal then be fixed to the mud? 8. In what other way may fractures in the rock be filled? 9. How do dykes differ from lava streams? [10. How does the possession of metals affect man?]

Lesson IV. Page 74.

1. Describe the two ways in which rain water goes away from the point where it fell. 2. Describe springs. 3. What may be said of the underground course of strong springs? 4. What rocks most favor the making of large springs? 5. What are caverns? 6. Where are the largest found? 7. What is the nature of the surface of a country beneath which caverns are found? 8. What are sink-holes, galleries, and domes? 9. How are the domes formed? 10. How do stalactites form? 11. How do they close the gallery? 12. What are natural bridges? 13. What is there remarkable about the animals of caves? 14. What are the movements of air into and out of the cavern due to? 15. How are the remains of animals preserved in caves? 16. What other sorts of caves occur, and how are they formed? 17. What is a "spouting horn"?

CHAPTER IV.

Lesson I. Page 88.

1. What part of the earth is known to us by sight? 2. What is a volcano? 3. What gas is most plentiful in volcanic eruptions? 4. Where are volcanoes found? 5. How do volcanoes originate? 6. What volcanoes are best known to us? 7. Describe the eruption of Vesuvius in 79. 8. What cities were buried? 9. Where is Stromboli? 10. Describe the flow of a lava stream. 11. What lava streams do we find in California? 12. What part do volcanoes take in the world's machinery?

Lesson II. Page 98.

1. What are the two forms of the earth's life? 2. Whence come almost all its motions? 3. What would be the effect of cutting off the heat of the sun? 4. In what way does the sun's force come to us? 5. What part comes from the fixed stars? 6. What part of the earth receives the most of the sun's heat? 7. What would happen if the sun's heat stayed where it fell? 8. What is the effect of the storage

of heat? 9. How does water carry heat away from the equator? 10. What does a paper balloon show us? 11. How can we compare the circulation of the atmosphere with the movement of the air about a heated stove? 12. How would the winds move if the earth stood still on its axis? 13. Why do the winds tend to the west in going south and to the east in going north? 14. How can this be illustrated? 15. How do the trade winds produce the ocean currents? 16. In what courses do these currents of the sea move? 17. How do the waters return to the equator? 18. How do the shapes of the lands influence the sea currents? 19. What would be the effect of lowering Alaska and the Aleutian Islands beneath the sea? 20. What are the other causes of changes in the climate? [21. What do you understand by climate?]

CHAPTER V.

Lesson I. Page 107.

1. What are hills? 2. How do they differ from mountains? 3. How do the beds of rock lie in mountains? 4. To what are mountains due? 5. What causes the crust to wrinkle? 6. How do we know that most things shrink in losing heat? 7. How do we know that most mountains rise slowly? 8. What are the Alleghenies like? 9. How do they differ from the Alps? 10. What happens when mountains cease to grow? 11. What help do mountains give to those who seek the minerals of the earth? 12. How much do the folds in the rocks differ in size? 13. How do continental folds differ from those of mountains? [14. What is the striking difference between the movement of heat from the earth's crust and that to the earth's crust from the sun?]

CHAPTER VI.

Lesson I. Page 113.

1. What should we observe in order to see how valleys are formed? 2. What happens when the lands rise out of the sea? 3. What are the principal parts of a river valley? 4. What do we see in a mountain stream? 5. What change is marked when the stream has less fall? 6. How is the alluvial plain made? 7. What is the delta? 8. How are falls formed? 9. How is Niagara formed? 10. How the Ohio falls? 11. What are "oxbows"? "moats"? 12. How are ter-

races formed? 13. How are cañons (pronounced *canyons*) formed? 14. Where is the best example? 15. How was the Yosemite Valley formed? 16. How are tidal valleys formed? 17. Where are good examples? 18. How do tides affect animal life?

Lesson II. Page 125.

1. What can be said of the way in which lakes are placed? 2. What are the important divisions of lakes? 3. Why are certain lakes salt? 4. What of salt deposits? 5. How were most of the lake basins north of 40° latitude formed? 6. What sort of a surface was given to the land by the glaciers, and why? [7. Why does a lake last but a short geological time?] [8. What will in time happen to the American Great Lakes?]

CHAPTER VII.

Lesson I. Page 130.

1. Describe the events of the Lisbon earthquake. 2. What are the three forms of danger in earthquakes? 3. Describe the great Mississippi earthquake of 1811. 4. What are the worst regions for earthquakes? 5. What action of the earth may produce the jarring motion of an earthquake? 6. What effect does it have on the animals of the sea? 7. How does it produce great waves? 8. What is the effect of these waves?

Lesson II. Page 141.

1. What is the best proof that the lands have once been sea-floors? 2. What can be said about a lift on the Chilian shore? 3. How does the sea take the lands back to itself? 4. What would happen if the Isthmus of Darien were to be lowered beneath the sea? 5. What would be the effect of lifting the Malay Archipelago so that a land bridge from Asia to Australia should be formed? [6. What is the effect of moving animals to new countries?]

CHAPTER VIII.

Lesson I. Page 146.

1. Whence comes the force that acts in organic life? 2. What are some of the effects of life on the earth? 3. What is the best proof of

the perfection of the earth's machinery? [4. Is it reasonable to suppose that this order is due to chance?]

Lesson II. Page 149.

1. By what marks are organic beings separated from the inanimate world? 2. Give the names of four animals that are closely akin. 3. Why are these akin? 4. Give a list of some not closely akin. 5. What are the contrivances for measuring time? 6. In what order of relations can you place them? 7. How many *plans* of animal structure can you name? [8. Can you classify a bee or a beetle?]

CHAPTER IX.

Lesson I. Page 155.

1. Contrast living things with things that have not life. 2. Why is there no gradual passage from the mineral to the living world? 3. What are the lowliest organized creatures like? 4. What were the first plants? 5. What is the most marked difference between animals and plants? 6. What do plants strive to do in their successive changes? 7. Compare a rose-bush and a sea-weed. 8. What are these changes for? 9. What are the changes in the seed? 10. What purpose do flowers and fruits serve? 11. How do the purposes of animals differ from those of plants? 12. What is the machinery of intelligence in an animal?

Lesson II. Page 164.

1. What are protozoa like? 2. What are radiates like? 3. What are the lowest radiates? 4. What the highest? 5. What about their motion? 6. What about their nervous systems? [7. What about their intelligence?]

Lesson III. Page 168.

1. Name some bivalve mollusks. 2. How do they differ from radiates? 3. What forms of bivalves move? 4. Name some single-shelled mollusks. 5. Why are they higher in structure than the bivalves? 6. What are the lowest land animals? 7. How do the squids differ from snails? 8. Why are they higher than snails? 9. How do they move? 10. What of their nervous system? 11. Why are mollusks as a whole higher animals than the radiates?

Lesson IV. Page 175.

1. Name some articulates. 2. How are they built? 3. How do the worms differ from the crustaceans? 4. How does an insect differ from a crab? 5. Give the names of a dozen different kinds of insects? 6. How do the minds of insects differ from those of the lower animals? [7. What is the reason they do not have a more important place in the world?] 8. Compare the articulates with the mollusks and the radiates.

Lesson V. Page 179.

1. What is the highest of the great groups of animals? 2. Why is it the highest? 3. What are the peculiar features of the fishes? 4. What are the amphibians? 5. What changes do they undergo? 6. What are the reptiles? 7. What power of motion do they have? 8. How do the birds differ from the reptiles? 9. What is the advantage of warm blood? 10. What is the highest group of animals? 11. How is it distinguished? 12. What are the lowest of the mammals? 13. Describe the advantages of the vertebrate skeleton. 14. How does the nervous system of vertebrates show itself better built than in lower animals? 15. How do vertebrates give help to their young? 16. Tell the succession of coming into life of the various groups of vertebrates. 17. When do the vertebrates first appear on the earth? 18. How do the means of speech in vertebrates compare with those of lower animals? 19. How does man differ from the lower animals? 20. How is he related to them? [21. How does his mind differ from the animal mind?]

CHAPTER X.

Lesson I. Page 189.

1. What animals leave no remains on the rocks? 2. What becomes of hard parts if they are left uncovered on the surface of the earth? 3. What do we find in an old forest? 4. What are the ways in which animals may become buried on the land? 5. Why are fossils more often formed on the sea than on the land? 6. How are fossils preserved? 7. How are they changed after they become deeply buried? 8. Of what use are fossils to the geologist? 9. What do they tell him? [10. What part of all the life that the earth has borne has been fossilized?]

CHAPTER XI.

Lesson I. Page 195.

1. How long have we known that life was a very ancient thing in the world? 2. Why must we believe that existing animals have sprung from the more ancient kinds that once existed, but no longer live? 3. What does the Darwinian theory suppose? 4. What do we find among our domestic animals that helps us to understand the changes of animals? 5. How do we know that life may become degraded as well as advanced? [6. Is there any similar truth in morals?]

Lesson II. Page 203.

1. How do conglomerates or pudding-stones and sandstones show that the earth is old? 2. How do limestones show it? 3. What do we learn from water-falls? 4. From the peninsula of Florida? 5. From the elevation of certain countries? 6. How does the history of life show us that the earth is very old? 7. How can we represent the earth's age in years by distance in feet? 8. How do the beds of rock give us clews to the history of the earth? 9. How many years of life can you remember? 10. What part is this of 1,000,000 years?

CHAPTER XII.

Lesson I. Page 209.

1. What was probably the first condition of the earth? 2. What do we learn from the planet Saturn? 3. How was the heat of the earth developed? 4. When did the water of the seas come upon the earth?

Lesson II. Page 213.

1. What are the oldest rocks called? 2. Where do we find the first certain evidences of life? 3. What animals were there in the seas? 4. What higher animals were wanting? 5. What change in life marks the Devonian period? 6. What marks the carboniferous age? 7. What important groups of animals appeared then? 8. What important groups of animals appear in the Triassic age? 9. What do the Connecticut Valley footprints teach us? 10. When did the first mammals appear? 11. What were they like? 12. What do the salt deposits of the Triassic time teach us? 13. What were the reptiles

of the Reptilian period like? 14. When do the birds first appear? 15. How did they differ from our living birds? 16. What advance took place in the plants of this time? 17. What changes in the land took place in the Cretaceous period? 18. When did the broad-leaved trees begin? 19. In passing from the Cretaceous to the Tertiary period, what was the great change in life? 20. Is it likely that these new forms of animals were suddenly created? 21. What common forms of animals were wanting in the lower Tertiary? 22. What was the nature of the mass of mammals at that time? 23. What were the successive changes by which the five-fingered foot became changed into a horse's foot? 24. What are the splint bones of the horse's foot? 25. What can be said about the advance of birds during the Tertiary period? 26. What about advance in the insects? 27. What about advance in the cephalopods? 28. What advance is seen in the plants?

APPENDIX.

Crystalline Rocks. Page 233.

1. What are the three physical states of matter? 2. In which state do crystals occur? 3. Give some instances of crystals. 4. What can be said of the shape of crystals of any one substance? 5. What do meteors show us? 6. What do we find in little-changed stratified rocks? 7. How are crystalline rocks made?

1. What is claystone? 2. How is slaty cleavage made? 3. How is limestone marble made? 4. What is the change that may be made in sandstone? 5. What are dykes? 6. What are veins? 7. Give the important points about the following minerals: quartz, felspar, mica, hornblende, pyroxine, calcite, dolomite, gypsum, common salt, pyrite, magnetite, hematite, limonite, siderite, copper, zinc, tin, gold, aluminium, sulphur. 8. Of what minerals are the following rocks composed: granite, syenite, gneiss, mica schist, porphyry, steatite, turpentine, quartzite? 9. How are these rocks and crystals destroyed? 10. How do they return to the crystalline state?

CHAPTER I.

PEBBLES, SAND, AND CLAY.

LESSON I.

RIVER PEBBLES.

LET us take a number of pebbles such as come from the bed of a river. We notice that they are of different shapes and of different colors and of many sizes. They are all hard and smooth, but some are smoother than others; some have faces that are nearly flat, and some are almost as round as marbles; some are all of the same sort of stone, and others are made up of several different kinds of stone mingled together. If we could see the way in which these pebbles were formed, we should know much of the history of the world.

Let us trace the history of these pebbles back into the past. It is a long story; for, between the time their making began and the hour in which they were taken from the water, a vast length of years has gone by. If we look at the stream-bed where these pebbles were found, we find that it is so full of them that its bottom and sides are in good part made up of such bits of stone. When they were taken out, they were slowly working down towards the sea. Every flood rolled them a little farther on their way, and were it not for the fact that they are from time to time caught on the sides of the stream, and held by the other stones laid on top of them, or tied by the roots of

plants, they would travel only a few years before they would be either worn out by the bruising they received on their rough journey, or rolled into the sea. But if we examine the banks of either side of the river, we find that there are great quantities of such pebbles as are now in the stream, that have been stopped in their journey, and built into the strip of level land that makes a plain on either side of the river. The chance was, that if these pebbles had been left where they were found, they too would have often been compelled to wait on the bank; because the stream does not always keep the same bed, but is continually

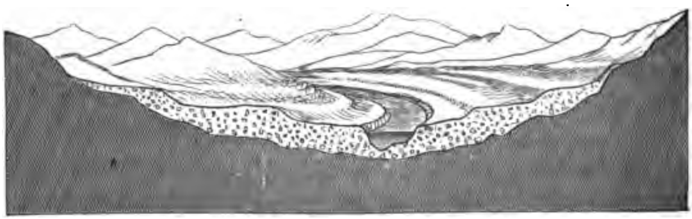


Fig. 1.
Section across River Valley.

cutting away on one side and filling in on the other. So that each pebble journeys a little way down stream, and then rests awhile on the bank; while other pebbles, that have been perhaps for thousands of years imprisoned in the bank, are taken out by the changing river and carried a way down stream, again to be put into their resting-places on the alluvial land.

Let us look for the place where these pebbles were found. As we go up stream we find the pebbles growing always larger and more angular, until at length we find them so heavy that only the swiftest-running waters can move them; this is because they wear away by rolling

over each other. This work is copied in the making of boys' marbles; and it is worth while to notice how in this, as in many other branches of labor, man succeeds in his tasks by imitating Nature. In making marbles, bits of square stone, all of about the same size and of even hardness, are put into a large drum through which a stream of water flows. This drum turns around like a wheel, causing the stones to rub over each other; the same amount of wear being given to every side, they come out spheres. It might seem at first that we ought to have the same shapes in the river-pebbles, but we notice that these are usually a little larger one way than they are the other; they are often so flattened that they are called "shingle." This is because stones are generally more easily worn in one direction than in the others. They are not equally soft on all sides. If we should turn them round on a lathe, and then put them in the marble-maker's drum, they would wear into oblong shapes. As soon as a stone is a little flattened, the water finds it easier to push it along on its side than to roll it over and over; so it wears it into the thin shapes we often find.

Going up the stream, we come to the part of its course where it no longer makes its bed in gravel and sand, but tumbles over the hard rocks. Here we can see the place where the making of the pebbles begins. We see large masses of stone that have been broken out of the cliffs that border the streams. These bits are of all sizes: some of them so small that the stream sends them bowling along down its bed; others great masses as large as a barrel, or larger, that lie still in its bed, and force the water to turn out of its way. When these great masses of stone are very solid, they may last for centuries without being harmed by the stream; but usually there are some very slight crevices

in the stone into which the water finds its way. During the summer season the water can do but little, but when the intense cold of winter comes, and all the stream is frozen to its bottom, this water in the crevice also freezes, and in so doing exerts power enough to split the stone in two. This force the ice has because water in freezing must expand by one-seventh its bulk; to get this greater space it will push things apart slowly, but with all the force of gunpowder. A bomb-shell can be broken by filling it with water, plugging up the hole with an iron screw, and putting it out of doors of a winter's night when the

Fig. 2. Section down a River Bed.

thermometer goes below zero. We often see how powerful it is from the bursting of frozen water-pipes.

This rending by the frost will soon break up most rocks to bits that the river in its flood-times can drive down its bed. But generally the stream grows less swift as it descends toward the sea, so that the stone is urged forward with less force than is necessary to move it. When this happens, it lies awhile until the frosts of other winters have divided it again.

It is this same frost that does the most of the work of breaking the stones out of the cliff sides, so that they may tumble into the brook.

LESSON II.

SEA PEBBLES.

We have now seen the most common way in which pebbles are formed; but there is another pebble-mill on the sea-shore that does much the same sort of work, though it makes pebbles of a somewhat different form.

If we go to the coast anywhere where the shore follows the wide sea, or around a lake large enough to form great

Fig. 3. Section of a Cliff Sea-shore.

waves,—on these coasts we find two sorts of shores: when the hard rocks jut out into the sea, there are steep cliffs against which the waves beat (see Fig. 3); but the larger part of the shore is shelving, being made of pebbles and sand. These shelving shores are called "beaches." They are of the form shown in the figure (see Fig. 4). As we stand on these shores we see that the waves, as they break upon it, run up the beach with great power, and then hurry back only to rush again up the slope and again return. If the waves be strong, this swashing to and fro carries the

water very swiftly up and down the slope ; and, as it goes, it rolls the pebbles with it. In heavy storms, stones as big as a man's head are easily rolled to and fro for two or three hundred feet of distance. In these storms, the smaller pebbles are often flung out with the foam beyond the sweep of the wave, making the ridge shown in the picture.

But most of the pebbles of the beach swing to and fro within the waves until they are ground to the finest bits. They are in a mill that never stops working. Although in the course of ages the shore moves about, it is really

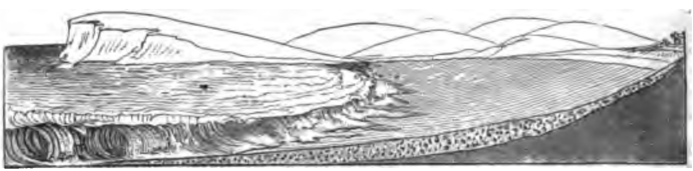


Fig. 4.
Section of a Sea Beach.

among the most enduring things of the world; for the waves of the sea have rolled in this fashion against the land ever since the seas were made. A pebble on the beach, unless it gets covered up by other pebbles, wears away very fast. It travels in times of calm a little distance every time the wave strikes; as this is, say, six times a minute, the stones move a few feet (we may average the distance at ten feet) in all weathers; they would thus travel between twelve and fifteen miles a day. We have only to listen, as the waves rush up and down, to hear the grinding of the pebbles against each other as they are rolled to and fro. It is not only the top pebbles that roll, but the

whole of the beach is moved to the depth of two or three feet. Sometimes the roar of the grinding stones can be heard several hundred feet away from the beach.

The ground-up pebbles make sand and mud, the history of which we shall follow hereafter. We will now go seeking for the origin of the beach pebbles, as we sought it in ascending the stream when we were finding the way in which river pebbles came to be. Nearly all beaches of the sea-shore are crescent-shaped, as in Fig. 4; they have at one or both ends of the horns the place where the pebbles begin to be made. We find these smallest in the bottom of the hollow, and they grow larger as we pass out toward the place where they begin to form; just as they grew larger as we went up the stream when looking for the place whence the river pebbles came. When we get to the end of the beach we find the beating sea-waves at work cutting out the stones of which the pebbles are to be made. If the rock be as soft as a gravel bank is, and many of the beaches of our northern coast are cut in gravelly beds, the sea has little work to do; the waves soon cut back into the cliff, when the overhanging mass slips down into the sea; then the pebbles are driven on to the beach, when their rolling to and fro begins. But when the rocks are hard, the sea has a good deal of work to do to force out the blocks of stone; but by taking those on which it gets a grip, and hurling them against the rock, it slowly but surely manages to cut back a groove so that the rocks overhang and fall of their own weight. When they fall, these masses of rock generally

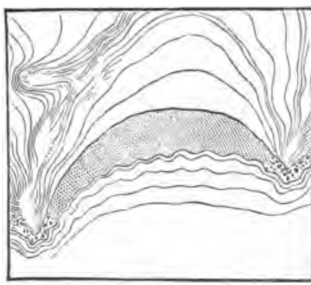


Fig. 5. Map of a Sea Beach.

break up into pieces that the waves can lift and hurl against the cliff, or against each other, until, by breaking, they become small enough to be kept in constant motion; then they are quickly crushed into pebbles, and rolled to the beach. Thus, the cliff part of the shore feeds the sea-beach, which is a sort of mill for grinding pebbles.

LESSON III.

GLACIAL PEBBLES.

THERE is a third kind of pebble that has a different history from either of the other two. It, too, is the work of water, but of water working in the very different form of ice. In the regions near the poles of the earth, and in the high-up valleys of some great mountains, we have snow that never melts from one year to another. This snow would make an immensely high mass if it had no way to escape; but a road for it to get into warmer regions where it can melt is provided in this way: —

The eternal snow-fields are always receiving snow both in summer and winter. This snow is pressed down by that which falls upon it, and by this pressure is turned into ice. We easily see how much harder and ice-like snow grows when pressed. A snow-ball, if squeezed hard, becomes a whitish ice, and the snow that gathers on our feet is almost as hard as ice. Now, a great mass of this hardened snow, lying on the sloping ground of the mountains, will flow down that slope, becoming more like pure ice as it goes downward. When it gets into the lower valleys, it is a true river of ice, that may be half a mile or more wide, and hundreds of feet deep. In the Alps and Himalayas these streams slowly creep for miles, sometimes for as much as thirty miles, down the valleys, until they come to regions warm enough to melt them away.

These streams of ice are called "glaciers," from the French word *glace*, which means *ice*. They move very slowly, not more than three or four feet a day. They are constantly breaking and soldering together, but still they move on, faster in summer and slower in winter, and so drain away the snow from the regions where it cannot melt. Out from beneath these glaciers there flows a stream. Its water is always very muddy, and it bears away many

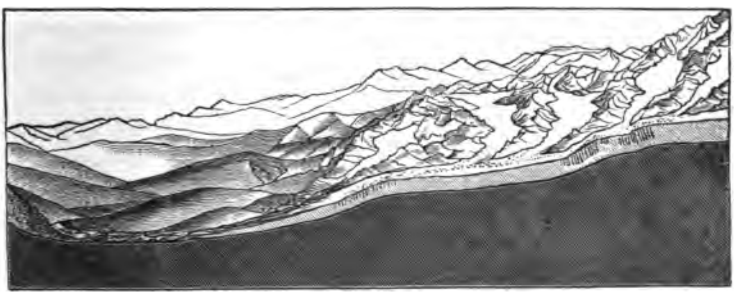


Fig. 6.
Section down a Glacier.

pebbles, which, with the rocks that have been carried on the surface of the ice, make great masses of stones called "moraines."

If we look closely at these pebbles, we may see that, though they somewhat resemble those from the rivers and the sea-shore, they are yet unlike them. These stones shaped beneath the ice are not so smooth and round as the others; they often have scratches upon them, as in the figure, which show that they have been held fast in the ice and pushed over some hard substance. (Fig. 7.) We can see the way these scratches are formed if we enter the cave out of which flows the stream that drains the glacier, and find a place where the ice rests on the rock.

This we can easily do on many a glacier. When the ice rests on the rock, we often find that it has grasped pebbles that are held firmly upon the rock and forced along over it. As the ice slowly melts when it touches the rock, because of the heat of the earth and the heat that comes from the rubbing that takes place there, these stones are pressed on by all the ice above them, so that a stone as big as an apple may have many tons of weight upon it.

These pebbles scratch the stone over which they are pushed, and in turn are scratched; and so, when they escape at the end of the glacier, they generally bear the

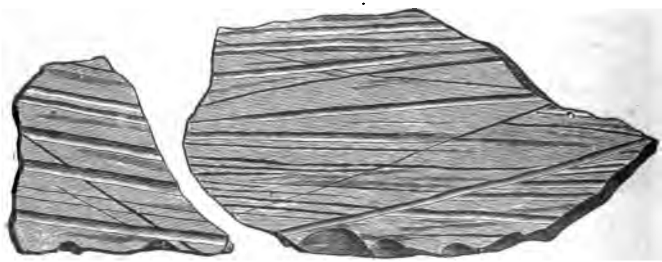


Fig. 7. **Rock surfaces scratched by Glaciers.**

marks of their struggle with the ice and rock. It is not every pebble that has been under the ice that bears these marks, for there are many that never get caught in this way, but are carried on by the stream that flows below the ice, or held up in the ice so that they are not against the rock.

These pebbles are made out of bits of stone torn out of the rock-bed over which the glacier flows, or that fall from the rocky sides of the mountain upon the surface of the ice, and then find their way through the cracks in the ice to the bed of the glacier.

Figure 6 shows an ice stream, with the heaps of stone

upon it that have fallen from the sides of the mountains, and which very often find their way down into the pebble factory at the base of the glacier.

The muddiness of the water flowing from beneath glaciers is noteworthy. This mud is made in the grinding of pebbles and sand in the way that we have seen. There is so much of it that every river in Switzerland which has glaciers on its headwaters is very muddy, while those that flow from lower mountains that have no ice streams are of crystal purity.

We have now seen how the pebbles are made beneath glaciers, and the reasons why they are more angular than those made by flowing water. We can easily believe that these scratched pebbles tell an important story when we find them in countries where there are at present no glaciers. As there is no other possible way in which pebbles can be so scratched, we may be sure that wherever we find them thus marked they show that glaciers once existed. Now, such scratched pebbles exist over a large part of North America and Europe, and other countries where there is now no trace of glaciers. If we take a line from New York City through Pennsylvania, and thence across the continent to St. Paul, Minn., then to the Black Hills, then south to the Rocky Mountains of Southern Colorado, then to the sea-shore at the mouth of the Columbia River, we may almost always find scratched pebbles along this line, and in nearly all the region to the north of it, as well as some few points to the south of it. If we search below the soil, in these countries, we often find the rocks still scratched by the work of the ice armed with these bits of stone. From these proofs we are certain that a thick sheet of ice once lay over all this country, and moved southwards, scratching pebbles and rocks as

it went. All through this region these glacial pebbles are very plenty, sometimes forming hills a hundred or more feet in height. So plentiful are these rudely-shaped pebbles in these northern countries, that we find more of them in the streams and on the sea-shore than either streams or sea can make for themselves. There are many times as many pebbles made by this ice-mill now, on the surface of North America, as have been made by the streams or waves and rivers combined. Indeed, a large part of the work now done by the rivers and sea-shore waves consists in shaping out and rearranging the pebbles that the ice has left over the land. We cannot now turn aside to consider the history of this wonderful ice time, for we intend to go only as far as the pebbles serve to show the way; yet we see that these bits of scratched stone, when we read them aright, open to us a wonderful chapter in the earth's history. So is it with all the things of this world. If we could see all that one of these little bits of stone has lived through, we should be able to look back through a mighty past, that would startle us with its strange scenes.

LESSON IV.

SAND.

WHILE looking at the history of pebbles, we often find ourselves in company with its numerous humbler kinsmen, the sand-grains. At first sight it might seem that these sand-grains are only little pebbles that are near the end of their long combat with the water, — that fight they wage so well, though in the end they are overcome;

but, when we look closely at them, we see that although there are pebbles no bigger than large grains of sand, a grain of sand is, after all, a different thing from a little pebble.

If we take some sand from a river, — where, as with pebbles, we will begin our study of sand, — we generally find, if we look closely, and especially if we take a common magnifying-glass to aid us, that these grains are sharp-angled, with flattened sides, and that they are generally like bits of glass, letting the light through them, though not exactly transparent. This shows us that sand-grains are in fact crystals, generally of a substance called quartz. We can easily satisfy ourselves that these grains are harder than most stones; by rubbing sand-grains upon the stones, they will scratch these stones without breaking the sharpness of the edges of the grains. The only change that comes over the grains is that many of them break into two or more pieces, which still preserve the sharpness of the larger bits. Even the powdery-looking stuff, if we look closely at it with a microscope, is seen to be made up of small, sharp bits.

If we compare the sand-grains with a tiny pebble of the same size, using a strong magnifying power to aid our sight, we find that the grains of sand are all composed of one like substance, while the pebble is made up of many grains of different sorts of substances. This substance of most sand is the same as glass; indeed, glass is made by melting sand, using some potash, soda, or lime only to aid the melting. We know how hard and cutting bits of glass are; sand-grains are even harder; for it is necessary to put some other substance into glass to make it melt easily, and this softens it somewhat.

As we go up-stream, searching for the place where the

sand is formed, we do not find the grains growing much larger, however far we have to go to find the place where it is made. This is a proof that the sand-grains do not wear so fast as the pebbles; for the lessening in the size of the pebbles as we go down stream is very marked. Often a good deal of the sand comes from the pebbles themselves; for these pebbles are often composed in part of quartz crystals, which break out in the shape of sand-grains when the pebbles are pushed along the bed of the stream and bruised against each other. But when a stream abounds in sharp sand, we shall find that along its course there are some rocks composed in part of quartz, such as granite, or syenite, or sandstone. When these rocks decay, they fall to pieces, and these grains of sand, being lighter than many other things that make rocks, are easily moved by the tiniest rills to the nearest stream, and they can journey down to the sea without any trouble. In all rivers that have anything to make sand of, along their banks, there is a constant stream of sand moving down to the sea, —more in times of flood than in low water, but always some. In the Arno, in Italy, on the banks of which these pages are written, we hav a good instance of this. Where the stream goes through Florence, it is a rather small river, indeed less than the Merrimac, the Mohawk, or the Great Miami rivers of America. A dam across the stream deadens the current, and helps the sand to settle to the bottom. Boatmen with long scoops are constantly taking out this sand from the pool below the dam, many cartloads a day being thus removed. But there is never any lack of new sand to fill the places; when one place is cleared, a few days suffice to fill it up again; yet this is not what would be called a very sandy river. In some parts of the Allegheny mountain country, where all the

rocks are sandy and decay quite rapidly, the streams carry so much sand that it is not possible to make a mill-pond that will be of any use, for the basin will be filled up in a few months' time.

As these sand-grains have sharp edges, and are harder than any other stones, they cut the stones they slip over. Whenever one stone is driven over another, there are generally some grains of sand below the rock to help to wear them away. The cutting power of a stream of water depends very much on the amount of sand or pebbles it has in it. If we drive a stream of pure water against a pane of glass, it will not affect it, even if we keep it moving at a high speed for days; but, if we have a little sand on it, the water will drive the sand against the glass, and in a few minutes it will appear like ground glass, from the cutting action of the sand. In the same way, the river-water gets a power of wearing stones. In a similar fashion, the sand is used in glass-cutting to shape figures on the surface of the glass. If the workman wishes to make a figure like a leaf, he pastes a paper on the glass, leaving the figure of a leaf bare. He then puts the glass in a blast of air, or steam, that drives sand at a high speed against it, and in a short time the bare part is cut so that it appears white, while the paper protects the rest of the surface from the cutting power of the sand.

LESSON V.

SAND OF THE SEA-SHORE.

NOWHERE else in the world can we see sand to so much advantage as on the sea-shore. Indeed, most shores seem at first sight like only sea and sand. On the sea-shore we

find the sand is the best friend the land has in its eternal combat with the sea. On far more than half the coasts of the world it forms a sort of armor, on which the pebble-armed sea can strike its blows without such destructive effects as it would bring about on bare rocks.

If we examine a beach when the surf is rolling in upon it, we may see how the sand resists the mighty blows *that* are struck against it. When the wave lifts itself into a great wall to tumble on to the beach, the hard grains of sand lie close together so compacted that the foot will hardly make a print upon them ; yet between the grains is a little cushion of water which keeps them from wearing against each other. When the blow is struck, the sand hardly feels the effect ; a part of it is stirred, but the grains are so wrapped about with water that they do not harm each other. If they were pebbles, they would pound against each other with a roar that we should hear above the sound of the waves; but the littleness and lightness of the sand gives it security. It is only when the sand gets between stones, that are pounded together by the waves, that it is much worn ; then some of its grains are ground to fine powder. The most of the sand we find on the sea-shore is made by this pounding of the stones together. In this pounding both stones and mud wear very rapidly, some part of each being ground into the fine powder we call "mud," a form of bruised stone which we have soon to consider.

Above the point where the waves beat most fiercely, where the broken water of the surf writhes hurriedly about in foaming eddies, the sand moves far more than when it receives the solid blow of the falling waves. Here, too, it moves but little, but it makes a mill where little pebbles and bits of shell, sea-weed, etc., are cut up by its sharp

points, and gradually ground into powder. This is an important work for the sand to do, as it makes a great deal of muddy matter, out of which the sea builds rocks, as we shall see hereafter. It also, by grinding up rubbish, keeps the sea-beach the clean, orderly place we always find it to be.

The heavy storms throw a good deal of sand above the level attained by ordinary waves. This becomes very dry; few plants can grow upon it, and these are killed by the next heavy storm. When the tides are low, the hot sun soon dries the exposed surface of sand down to near

Fig. 8. Dunes that destroyed Eccles, Norfolk, England.

the level of low tide. When the wind blows strongly from the sea, it moves this sand before it. We can at such times see little streams of blown sand moving up the beach until they are beyond the reach of the waves. This sand helps to make the high beach wall that often lies along the shore. On most shores the winds from the land side soon blow most of this back into the water. But if it happens that the winds from the sea are more powerful than those from the land, this sand keeps working inland, and gathers into great heaps called "dunes." These dunes are sometimes more than a hundred feet high, and miles in length. (Fig. 8.) The sand from the seaward side keeps blowing over

to the landward side, and so the dunes slowly wend away from the sea-shore, sometimes marching slowly inland and overwhelming fields and villages as they go. On the Atlantic coast of North America the winds are generally from the west, hence the dunes do not often have a chance to form, for the sand is blown out to sea. But in Europe, the same west winds carry the sand inland. In the head of the Bay of Biscay these sand-heaps are of very great size, and have covered a great deal of land. But for certain plants which flourish even on the sand, and tend to bind it together, it would not be possible to save many fertile regions from these dunes; but the grasses knit them together in a firm way, so that the wind cannot move them. If by any chance a hole is made in this covering of grass, the wind getting into it will sometimes tear the hill away. Even a footstep will sometimes start the break in the bonds the grass puts upon it.

On the land side the wind tends to take the sand away from the shore; and on the sea side the currents of the water, especially of the tides, work to pull the sand out to sea. We find, by drawing up specimens of the bottom in dredges, that the sea-floor, for hundreds of miles from the land, is covered by sands that wander to and fro in the sway of the currents that sweep near the shore. These sands have all been formed in the course of ages along the shores or in the rivers. But the most of the work of making sand is probably done on the surface of the land by the decay of the rocks, which fall into sand, and are then carried by the streams into the sea; where, because of its fineness and lightness, it may easily wander very far even in slight currents.

If we take up a little of any soil, we are pretty sure to find that it is partly composed of sand. In most regions this

sand is always part of the soil. So we see how universal this sort of matter is in the world. If by any change of climate a soil becomes too dry for plants to live, as in the Sahara Desert, then the soil becomes the prey of the winds, that sweep it about and make great dunes of moving sand and finer dust. These, as well as the sea-sands, may blow into fertile countries and reduce them to deserts. In this way the African deserts are always trying to gain

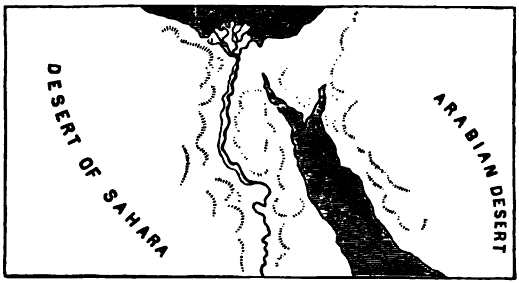


Fig. 9. Nile Delta and neighboring Deserts.

on the fertile land of Egypt. If it were not for the plants that hold the soil down, so that the wind cannot get hold of it, all our earth's surface would be as uneasy as the sands of the Sahara.

Sand is also plentifully formed beneath glaciers, even more plentifully than on the shores or in the streams, for there the pressure is far greater, and the stones are easily crushed by it.

When the sand is sharp, and blown in quantities by the wind, it sometimes cuts the rocks a good deal. In some parts of the Rocky Mountains it polishes and scratches the stones in the process. On some shores, when the wind blows along the coast, the pebbles are slowly worn away by the sharp grains that are constantly swept over them.

LESSON VI.

MUD.

As the sand comes below the pebbles in size, so these mud grains, which we are about to study, are less than the sand. Mud grains are so small that we cannot see them well without the microscope, and they have none of the charm for the eye that belongs to clean pebbles or sharp sand; yet, like all other things that at first sight seem to want beauty, mud is full of interest and of beauty, too, when we come to understand it.

If we put some mud under the microscope, we find that it is composed of small powdered and battered grains of rock, many kinds commonly being mingled together in the mass. We see that some of the bits are like little pebbles, being composed of several sorts of stone in the same piece; others are very small fragments of sand that have become decayed and softened after their long battle with the waters. We also often find little bits of plants, fragments of shells, etc. In other words, mud is the result of the constant battering that serves to break the fragments of rock into small pieces, and of the decay that constantly divides the bits into yet smaller particles.

If we put a little of this mud into water, we see that, unlike sand and pebbles, it does not at once fall to the bottom of the vessel, but remains like a cloud, only slowly settling to the bottom. Some of it will go down in a few minutes, some will fall in a day, but even in a bottle only six inches high there will be some that will require a day to find its way to the bottom.

If we go to any stream, we shall find that, if it be a

mountain brook, there will be but little mud, and that coarse grained. Stirring the water, we find that the cloud of mud that is raised quickly falls to the bottom, showing that it is coarse grained. This is because the finely divided rock easily runs away in the swiftly flowing water, and is carried off as fast as it is made. Going down stream to where the water flows more slowly, we shall find the mud becoming finer and finer, as is shown by the fact that, if we stir the bottom, the water will remain muddy for a longer time. As we go towards the mouth of a large river, such as the Mississippi, we find the water, though it moves slowly, is always clouded with mud, and the banks are, in the main, made of mud of the finest sort. Such a stream is always rolling out to sea a great mass of this mud, so finely divided that it may stay afloat for weeks and months, and thus be carried to distant parts of the sea.

This finely divided rock which we see as mud is abundantly formed on the sea-shores, as well as in the streams. The stones grinding together wear into this shape, and the sand that is rubbed between them has the same fate. We see little of the mud on the shore, because the currents formed by the tides and winds easily bear it out to sea; but, at very low tide, we often see very broad flats made entirely of mud; and, if we look in the bays along the shore, we often find that thousands of acres of land have been built by the mud that has been drifted in from the sea by the tidal currents, and caught by the salt-water plants. Yet more of this mud from the shore goes far off to sea, and falls on to the deep ocean floors.

Yet the most of the mud is not ground up by the sea-waves, or the rubbing of stones on the river-bed. It is made in and beneath the soil, by the action of decay,

brought about by water, and also by the work of plants and animals. If we take some soil from a field, and dissolve it in water, we find that it is partly composed of sand, in part of decayed plants, but in yet larger part of grains of mud. These mud grains generally make up more than half the whole. In all fertile soils they are much more than half the total mass. If we look closely, we may see what are the means whereby these mud grains are made.

When water goes through the layer of decaying plants, it takes up certain acids from it. These acids are formed by the decay of the dead plants in the soil. By these acids, as well as by the oxygen, which in part composes it, water has a very great power of rotting the rocks into fine powder. This process is called oxidizing. A familiar instance of it is seen when iron rusts in the ground. When the ground freezes and thaws, this dividing of the stones is greatly helped; for, the water soaking into them, and then swelling when it turns into ice, bursts them into dust. Then a singular work is done by the earth-worms. These creatures get their living by eating their way through the soil. They take the earth into their stomachs, take from it what there may be that they can digest; they then cast the earth out again; but, while in their bodies, the earth is exposed to the acids which serve to digest the food, and is more finely divided. Now, as in most soils there are many thousands of these worms to the acre, and as they are always at work, except when the ground is frozen, it is reckoned that they pass all the soil on which they live through their bodies every few years. There is no doubt that these humble creatures do a work that is fit to be compared with that of the rivers or sea-shores, in grinding up the elements of the earth into the finest mud.

In this work of dividing the fine grains of the soil the roots of plants also take an important share. The little fibrils that the roots put out are very slender, — sometimes so small that the eye can just perceive them. These, entering into the crevices of the mud grains, grow larger, and, as they expand, burst them apart. The roots of the larger plants, as they grow larger, exert an immense force. They may pry rocks apart as if they were wedges of steel. We see a little of their power on the streets, when they sometimes lift the paving stones. The first little thread of the root is so slender that it can insert itself into the crevices that lie between the grains of sand and mud; and, once there, it can soon gather power to rend them.

The largest share of the mud we find in a river is not made in its bed, but is carried from the land by the rains, which very easily dissolve it and convey it away. We have only to watch a plowed field to see how large the amount is that goes away with every rain. Were it not that the forces that break up the rocks into this mud are always at work, there would soon be no place for the plants to grow, so fast do the streams carry it away.

We have now seen in part how the machinery of the waters, aided by other forces, such as frost, roots, and the stomachs of worms, serve to divide up the rocks of the earth into very tiny bits, that can be easily carried by water. When in this divided state, a good part of the matter tarries on the land, and helps make our soils; the rest goes to the sea, and helps make the rocks that are constantly forming there.

We will now turn aside to consider the history of soils, for on them depends all the usefulness of the world to man. Then, afterwards, we will see what becomes of the mud and sand that goes from the rivers and shores to the depths of the seas.

LESSON VII.

SOILS.

The most important result of this battle, that is waged against the rocks by the air, rain, etc., is the chance it gives for life to find a place on earth. All the vegetable life of the land depends upon the existence of soils, and all the animal life would have no chance to exist, if it were not for the plants. Indeed, much, if not the most of the life of the sea, as we shall find further on, is fed by the things the soils produce.

In any field we have one of the common shapes which this layer of earth takes on the earth's surface. If we look at it closely, we see that there is on the top a layer of a very dark color, which we at once know has its color given to it by the decayed plants it contains. These plants turn black as they rot; and, though they break up into small bits, we can still see on the surface that they are bits of plants. This is plain, for the plants are not altogether decayed, and keep their shape. As we go downward, these bits of dead plants gradually pass into a brownish mould. As we dig yet deeper, this disappears, and we have the earth without any mixture of plant-fragments, but only colored by the stain of decayed plants. As we go yet further down, the soil becomes harder, until we come to the rock. This rock is generally soft at the top, and broken up by the roots that work into it. Below this level it is found to be quite solid.

This is the common sort of soil over all the world, except on certain regions, of which we shall speak presently. Such a soil is made by the gradual decay of the rock. If

we should strip it all away down to the solid rock, it would begin to form again in the following way: After a few years' exposure to the air, the stone would decay a little, and the seeds of lichens falling upon it would find a little softened rock to fix themselves upon. These simple plants need no soil, for they have no roots; they only need a roughened stone to fix themselves upon. They soon make a close net over the surface, so that it is quite hidden from sight. They keep the surface moist, and the acids made in the water by their decay help to rot the stone. Soon there is a little earth gathered in the small hollows of the rock; and, in these, grasses and low shrubs find a foothold. These, with their roots, help to break up the decaying stones, so that they may rot the faster. It takes many years, perhaps centuries, to get this beginning. These larger plants, when they die, make a mould that grows thicker and thicker as time goes on, so that it comes to be fit for the roots of trees. The seeds of pines, poplars, willows, and other trees with seeds so small that they need little covering, and so light that they can be carried by the wind, are constantly trying to find places to grow; and, as fast as this soil grows thick enough for their use, they spring up upon it. Soon we have the beginning of a forest, which is at first very stunted, because the soil is so thin. But this soil now grows rapidly in two ways: first, by the decay of the leaves of the trees, as well as by their trunks and branches when they die; and, secondly, by the action of the roots, as well as of the frosts, in breaking up the stones at the bottom, so that they may rot the faster. The breaking up of the stones helps the rotting by adding to the surface over which decay goes on. If we have a solid mass of rock like a floor, it rots only over its surface; if it breaks up into bits, the surface over which the

decay goes on may be ten or twenty times as large, and the decaying equally increased in rate.

All the while the rock is breaking up into bits in this fashion, the rain-water is washing through it, becoming soaked full of acids as it passes through the decaying bed of leaves, and with them dissolving the rock into its waters. In this shape the substances of the soil are ready to be taken into the plant through its tender roots. If the plants are numerous, and the water goes slowly through the soil, a good deal of this stuff the water takes into solution is caught up by the plants into their bodies, and for a while rests above the soil in the light of the sun. By and by it falls by death, decays, and the ceaselessly acting water has another chance to drag it down with it to the sea. All the water that runs from the ground in springs takes some part of this plant-food with it which the soil never recovers; but, while it robs the soil of a part of its richness, it gives more than it takes, by its effect in helping the decay of the rocks.

The richness of soil depends upon two things: first and foremost, on the nature of the rock below it, that is to say, on the kind of substances that the rock has in it. If the rock be a limestone with a great many fossils, it is sure to do its part of the soil-making in a perfect way, and give a fertile earth. Next, the soil depends on the action of the plants which yield it the vegetable matter, without which the rocks alone could not make the soil rich, for it is the acids that the water gains from the decaying plants that enables it to dissolve a sufficient part of the materials, so that the plants can get a hold on them. Of all the mass of a soil, probably not more than the thousandth part is at any one moment ready for plant-food. The greater part stays undissolved, and it only slowly goes into the shape of food for the plants.

Let us see now what is done when man comes to use the soil for the crops on which depend all his arts. The rudest savage ranges through the forest, and takes only its fruits and its wild animals; but such peoples are rare. Almost every tribe in the world gets some profit out of the soil by tillage. This can only be done by stripping away the natural plants, and using their place for those which suit man's needs. On the perfection of his methods in this work depends all his chances of civilization and wealth; for, however much wealth and culture are at times separated from agriculture, they always have their roots in this art, even as the trees, however high, depend on the earth beneath. When he tills the soil, man destroys its old natural state, and makes all its processes somewhat unnatural. When the plants are stripped away the rain no longer does the same work of creation alone, but it becomes a destroyer. The sponge-like mass of dead leaves, twigs, and trunks that make up a forest bed, holds the running water away from the soil, until it gets into considerable streams. These generally cut down into the rock, and so harm the soil but little; they eat only a little away along the river-banks. When the soil is tilled, the rain strikes on the surface of the bare earth, and sweeps great quantities into the streams. If the hills be steep, we often see the whole soil upon them carried away, leaving the bare rock, thus destroying in a few years the slow work of ages. When the soil is upturned by the plow, it is left very open, so that the process of decay goes on rapidly, and it is possible for a great deal of the soil to come into the shape for plant-food; but the rain is the more able to bear it away, and so the soil loses many things that are necessary for plants. Now the crops take away much of the rarer kinds of substances that are

necessary for plant-life. While soils are always gaining in depth and fertility, when in their natural crop of grass or forests, they are always becoming less deep and less fertile under ordinary tillage. The result is that a great deal of the soil of the earth that once was very fertile has been ruined by the plow. A skilful agriculture, that takes pains that the rains do not wash the soils away, nor the crops take away more than the natural work of decay puts into a state for plant-food, may be maintained with little loss of the earth's fertility for thousands of years. In England, France, and Belgium, where the soils have been carefully husbanded, they yield as much to the acre as they did a thousand years ago or more; but, in America, the tillage is generally very careless, because soils are cheap, and a great deal of the land is ruined, to the permanent loss of all the world in this and in ages yet to come.

It is worth while to look closely to this matter of soils, for on them depends the future of all countries and the life of man.

While the process of soil-making which we have described is the method that is followed wherever the soil is constructed on solid rock, there are other and rarer methods followed in particular parts of the earth. Along the river valleys, for instance, there is a strip of what is called alluvial land, which has been made by the earth brought down by the stream. This consists of a very deep mass of finely divided sand, pebbles, and mud, and in it the plants have no hard task of breaking up the rock, nor do they have to wait for the work of the frost, or other decay; for the amount of finely divided matter is so great, and the layer so deep, that the plants never get to the bottom of it. Indeed, this matter of the alluvial lands is, for the most part, the soil that has been washed away

from regions further up the stream, and left here because the river had more to carry than it could manage to bear along. Such soils are almost inexhaustible. Then, in the regions where the ice of the glacial sheet has acted, there are large tracts that are covered by a great thickness of sand and gravel, so that the plants never get access to the bed rock, and have not to wait long for the decay to form the materials out of which to make a soil. These soils are generally less fertile than the other lands; but, because of the great depth of the substances of which they are made, they rarely become less fertile than they were at first. Thus, the New England soils cannot be worn out as those of South America or Virginia, although in the first place they were not so rich.

We may gather up this account of soils in the following words: Soils are the wreckage of the rocks, as they wear down under the action of air, rain and frost, the roots of plants, and the stomachs of earth-worms. This wearing has been going on for a very long time in the past, so that the soil now on any country may have gradually settled downwards for thousands of feet, as the rocks slowly rotted away and were carried off by the streams. It is a beautiful fact that the greatest work of ruin that the world knows — the decay of the continents themselves — should give us the foundations on which to rest all the higher life of the world. All our forests and prairies owe their life to this decay. All the higher animals of the world depend upon this plant-life, and man himself founds his life upon the same mass of ruin. Thus it is through all the life of the world: the death of one thing gives life to others; the decay of the physical world is the foundation for the higher life of plant and animal.

CHAPTER II.

THE MAKING OF ROCKS.

LESSON I.

CONGLOMERATE.

PEBBLES have been studied in the first lesson, but we stopped our study with the loose pebble, as it lay on the river-bottom, the sea-shore, or where the glacier left it. But, as we can see from any specimen, pebbles may take on other shapes. They may be bound together so as to form rocks of a very solid sort, which are termed *conglomerates* or *pudding-stones*, so called because of the plum-like look of the pebbles in the mass. There are some beds of rock in the earth's crust, of very great extent, that are full of these pebbles. One of these sets of rocks is known as the millstone grit, because it is often used for making the stones with which grain is ground. These millstone grits lie under the great coal-beds, whence comes the most of the coal used in the world. There are many other great sets of rocks made of the same sort of pebbly beds. Indeed, it seems that there are pebble-making times in the earth's history, when these bits of rock are made in such quantities that it is hard to account for their production. It is now believed that these pebbly ages are the times when glaciers are peculiarly abundant on the earth, for there is no other machinery that is so well fitted to make them. It is evident that the conglomerates are

mostly made in salt water; and the only way in which such vast masses of pebbles can get into salt water, is through the action of glaciers. The great rivers do not send pebbles into the sea. None much larger than sand find their way out of the Mississippi River into the Gulf of Mexico. The sea-shores grind up about all that they receive, so that we cannot look to them for the making of the great conglomerate beds.

We see, from specimens of conglomerate, that the pebbles are bound together by a sort of cement which generally consists of sand and clay, the whole forming a very hard mass. If we take common pebbles, sand, and clay, and mingle them together, we do not have this solid mass. How, then, could this mixture have become thus hard? This hardness of stones made out of bits that were not at first bound together is explained in part by the pressure that is put upon them when they are buried in the earth. These rocks were once deeply buried beneath a great thickness of other rocks, that have since been worn away by the action of the frost, rivers, and the sea-waves. For a long time thousands of feet of beds lay on top of these compacted rocks, squeezing their mass more powerfully than we can do it by any machinery. We see, in the making of brick or artificial stone, that pressure will very much harden the mass. Then the rocks have generally been heated. This heating took place in this way: The depths of the earth are very hot. We find in mines and deep wells that the heat grows one

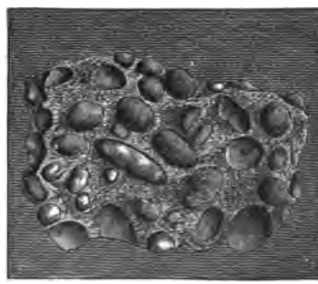


Fig. 10. Conglomerate.

degree higher for about each sixty feet of depth; so that, if these rocks are buried under twenty thousand feet, or about four miles of rocks, they will lie in a temperature of about 300° Fahrenheit, or 88° above boiling water. Some of these pudding-stones have had a yet higher temperature. We see in brick-burning how the heat binds the mass of soft clay together. Then, in the making of artificial stones, it is the custom to use a certain amount of either silicate of potash, called *soluble glass*, or silicate of magnesia, which hardens like cement, and so binds the stuff together. This is imitated from the processes of the earth, for it is just the way in which the rocks are often hardened.

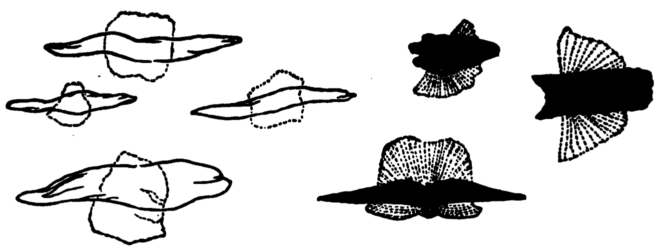


Fig. 11. Pebbles and shell elongated by pressure (dotted lines show original shape).

Sometimes we find, in the way the stones behave, proof that the rocks have had great heat and pressure. They often stretch out until, from their original egg-shape, they become like ribbons. At other times, the pebbles of the hardest rocks have been pushed into each other. When these pudding-stones wear away, the pebbles fall out, and are buried in other deposits, so that the same pebbles sometimes find their way out of one bed of rocks and into another of a later age, until at length they are destroyed by the grinding on some sea-beach, or worn

out in their long journey down some river, or else they rot to pieces.

As a pebble grows smaller it gets better able to stand the wear and tear that the world gives to it. A large pebble strikes hard blows when it is swung by the sea or rolled by a river, and so wears rapidly; but the little ones are less heavily beaten. Besides, it is always the very hardest part of a pebble that wears to the end, so the small bits are the best fitted to wear. The smaller a thing is in the battle with the waters of the earth, the safer it is in the fight; for, as we have seen, sand wears very slowly, on account of the small size of its grains.

LESSON II.

SANDSTONES.

We have seen the sands of the sea and of the rivers in constant motion; we have now to notice them in the state of repose, in which they are when built into solid rocks. In this shape they make up a large part of the visible crust of the earth. Sandstones are more plentiful than any other rocks on the land, as sand seems more plentiful on the rivers and along the sea-shore than any other substance. Sometimes these sandstones are in the shape of very soft rocks, the grains hardly holding together. Again, they are very firmly bound to each other, and at times the divisions between the grains are hardly visible, the whole then forming a very solid mass.

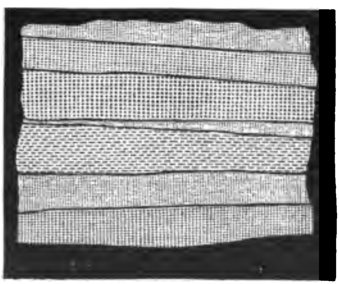


Fig. 12. Sandstone.

When these sandstones are looked upon closely, we see that they always show a certain sort of bedding, as is indicated in the figure. These are the great distinct strata, as we may find in the limestones and clay-stones; but, besides these, we have also in the sandstones what is called "cross bedding." This is shown in Fig. 13. We see, besides the large separate beds, that there are sloping divisions that run across them. If we would understand how this works, we should watch the sand running in a sandy gutter of a rainy day. We shall see that the bed of sand builds out at the end in sloping banks.

The arrow shows the direction of the current, and the letters *a*, *b*, *c*, *d*, *e*, the successive layers put on one after the other. If we should find a bed below, that had the cross lines sloping the other way, we should be sure that when it was formed the stream ran contrary to the course of the one that is forming. In this way, in sandstones even of the oldest day, we are able to tell which way the currents ran that brought the sands to their place.

These old sandstones supply a large part of the sand that we find in the rivers and on the sea-shore. The rocks

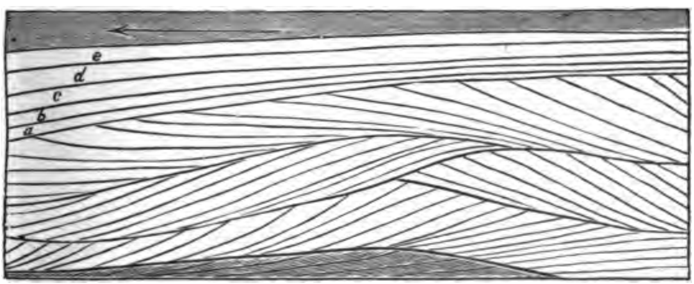


Fig. 13. Cross-bedded Sandstone.

decay under the soil, along the rivers and on the sea-shore; but the grains that compose them live on and take shape again in rocks, there to rest for ages; but again to be swept out by the water, and brought once more into the active world.

Sandstones are found over so wide a surface of the world because sands are so easily carried by the waters. Conglomerates are always in rather narrow strips, because they are generally formed along the shore lines, the currents not being able to carry the pebbles that compose them far to sea.

LESSON III.

MUD STONES.

We have seen that pebbles and sand both exist on the earth in two shapes: in one they are moving in the rivers and on the sea-shore in constant unrest and decay; in the other they are motionless in the rocks, scarcely changing in millions of years. Water, which, by its motion, forms pebbles and sand, serves also to take them from this state of rest, and return them to the state of activity. The same thing occurs with the finest state of rocks, called mud. Mud is buried in beds firmly bound together, and after a time is lifted into the continents and mountains, to be called from its resting-places by the streams and frosts, or by the decay that takes place beneath the soil. The clay-stones are found over a wider field than either the sandy or pebbly rocks, for the reason that the currents of the sea can carry this fine sediment much further than it can sand, as they can carry sand very much further than they can carry pebbles. When the sand goes out of rivers or drifts off from the sea-shores, it cannot travel far before it must come to rest on the bottom of the sea. But this mud can go much further. Indeed, some of it is constantly dropping over all the sea-floors. The volcanoes which are so plentiful along the shores and on the islands of the oceans throw out a great deal of dust, which is sometimes so light that it will float thousands of miles through the air before it falls to the ground or sea. In the sea-water it will fall even more slowly than in the air. It may be months in getting to the bottom; and, as the sea-water is always moving, it may be carried thousands of miles away

from the place where it alights on the surface, before it finds a resting-place. These volcanoes also give out a great deal of what is called *pumice*. This is stone which, when it was melted, became so full of air-bubbles that it would float like cork. This pumice cannot get to the bottom until it rots, which may require tens of years. It does not fall all at once to the bottom, but the surface decays, and falls off in fine grains that slowly sink to the sea-floor. Only when it is much decayed will it sink to the bottom. Thus, those parts of the sea-floor that are far from land have a little mud constantly coming down upon them. These mud deposits form very slowly; an inch may take many years to build; so that, when we see a bed of fine-grained claystone, we may generally be sure that the time taken in its building must have been much greater than if it had been made of sand, and a bed of sand or lime requires more time than one of pebbles in its making. These beds of clay slate, not thicker than roofing slate, may have required many years, perhaps a century, in their formation. This may give a measure of geological time. When we remember that there are many sheets of clay slate that are thousands of feet thick, we may conceive how long it took them to be built in the old sea-floors where they were formed.

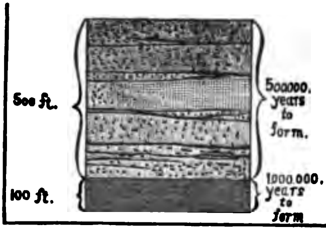


Fig. 14. Rate of Deposition.

LESSON IV.

LIMESTONE.

So far we have only noticed the ways by which certain rocks were made by the action of water, frost, waves, and other causes, upon the rocks that form the land. We have seen that through the work of the water a certain part of these rocks is constantly passing into the state of sand, pebbles, or mud, and then, after a journey in the keeping of this water, falls to the sea-floor or to the bottom of lakes, to be built into rocks again.

There is another sort of rocks we must now study, that differs very widely from those before described. These are the limestones, or rocks containing lime, that abound in every part of the earth. The rivers and the sea-shores, that show us the ways in which the other rocks are made, give us little clew to the origin of limestones.

Fig. 15. Limestone made of Shells.

If we look closely at the structure of limestones, we see that they have several different shapes. In the commoner kind the mass of rock consists of little grains as fine as mud, and mingled with them we can almost always find some small bits of shells, or corals; sometimes, though rarely, the bones of fishes and quadrupeds. This rock is

usually quite solid. If we burn it, a great quantity of carbonic acid gas and some steam escapes, and we have the lime used in making mortar. If we put it in certain acids, the lime is dissolved, and there remains some clay or mud, just like that we find in clay-stones.

To see the way in which these limestones are formed, we should go to the tropical seas of the world, where the warm water holds a great deal of animal life. Most of the creatures living in those seas have a certain amount of lime built into their bodies. Sometimes this lime serves as a protection to the body of the animal against its foes, as is the case with all the shell-fishes or mollusks,

Fig. 16. Limestone Building Corals.

or as a solid support for a community of polyps, as in the branched corals; sometimes as a skeleton, to support the soft parts of the body, as in the true fishes. When death overtakes these creatures, their heavy skeletons fall upon the sea-floor. On this floor there is a host of animals that get their living by eating these remains of other animals. They bore them through and through, and finally reduce them to a limestone mud. Only now and then do we find specimens that have been well preserved; but, if we examine it with a microscope, we see that almost any bit of the limestone shows that it has been alive.

Some of these lime-gathering animals grow very fast. An oyster as big as a man's hand may grow in a year or

two; a great mass of coral branches may be made in a few years, so that the amount of the lime that is brought by them to the sea-floor is in some places very great.

The coral reefs are among the most active in this work of building limestones. These coral reefs are the most wonderful things that the seas contain, rich as they are in strange creations. They are found in two forms: as strips along the shores of the continents and islands, called "fringing" or "barrier reefs," or as solitary islands far out in the deep seas, called "atols." The figures give an idea of the shape of these reefs. The corals that make them are star-shaped

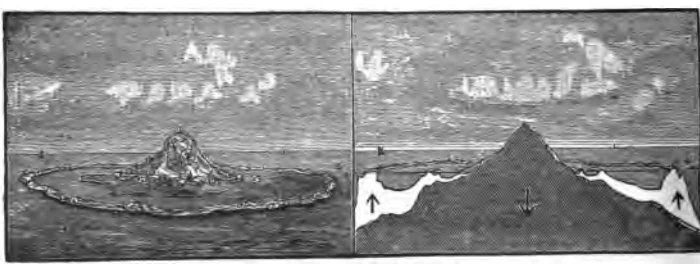


Fig. 17. Barrier Reefs and Section of same.

animals that are akin to our sea-anemones. They live in colonies, their bodies united together resembling a bush with many buds on its several stems. Each colony has a framework of limestone, like those shown in the figures. Some of these frameworks are so strong that they withstand the beat of the greatest waves that the broad oceans hurl against them. Wherever the ocean sends currents of warm water against the shores, these coral reefs abound. On the eastern shore of Australia there is one over a thousand miles long. In the Pacific and Indian Oceans are thousands of islands built by coral animals. These have been formed around volcanic or other islands, that have

slowly sunk down into the sea, while the corals have steadily built up towards the surface. They are generally ring-shaped, with a bit of still water fenced around with the ridge of coral. The way in which these coral islands are formed is shown in the figures.

Each of these great coral towers of the sea is alive only at the top, and for a hundred feet or so below the water; but this crown of living corals supplies a vast amount of limestone to the sea. The waves break away branches from the corals, and throw them up on the beach where they are ground to powder. There is a strong current sweeping by these islands, which carries this powdered lime away, to deposit it far over the sea-floors. These great reefs can grow only where there is a strong motion to the warm water; for they need a great deal of food, which they can get only in the sea-water moving by their mouths. As it goes by, they, with their tentacles, snatch at the tiny creatures that fill the water, and take them into their mouths. This current, which generally runs at the rate of two to four miles an hour, not only serves to feed these vast collections of polyps, but also to bear away the limestone mud formed on the shores of the islands by the beating of the sea-waves.

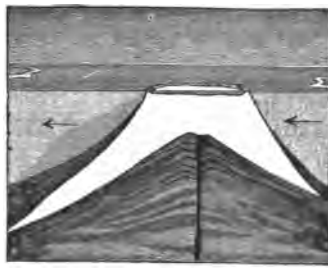


Fig. 18. Atol Reef.

These coral communities, or atols, as they are termed, are prodigiously high and steep mountains rising from the floor of the deep ocean. If we could drain away the waters of the Pacific Ocean, and walk over its floor, we should see them rising like great towers, with sides so

steep that we could hardly climb them; and, on their broad, flat tops, a shallow cup, as is shown in the figures. We do not know just how many of these coral islands there are, but it is likely that there are over five thousand, and they may number ten thousand. If we include with them the reefs that are fixed to the shores, their coast lines, if put together, would probably stretch for a hundred thousand miles. On all these shores the waves are ever beating, making clouds of fine mud that stream over the seas, and fall to the bottom to make limestones.

These coral reefs are no new things on the earth. From very remote ages the seas have been beating on their shores, and taking the lime that they separated from the waters, and building rocks of it. Nor are they the most powerful agents of making limestones, though they are by far the most grand examples of the power of life in its work on the earth's surface. Still, these coral reefs do not make the most of the lime deposits. The greater part of the limestone making is done by the smallest and simplest forms of life, that live scattered through the sea-water, or on the floors of the oceans. Of these creatures there is an amazing variety. Thousands of species contribute to the work, each by giving its particular form of body to make up the mass of the sediment that comes direct to the sea-floor and makes limestones. The most effective of these limestone makers are certain very simple animals, called "foraminifera." These creatures are, as far as our limited means of knowing go, mere bits of living jelly,

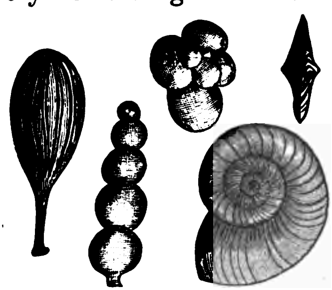


Fig. 19. Foraminifera.

without mouths, stomachs, or any senses; but they form about them beautiful shells of lime, showing that they are really far more complicated than they appear. These foraminifera live in myriads in the sea-water, from pole to pole, and when they die, their shells fall like little flakes of snow down on to the sea-floor in a slow shower that has probably never ceased since the earliest ages.

On the sea-floor there are many other forms that make a great deal of lime. There are small solitary corals, like those shown in the figures, and sometimes fields of crinoids, standing like tall grain with branching heads tangled together. All these and many more shells, corals, etc., kinds that cannot be noticed here, make up the multitudinous life of the sea-floor. They all give something to the great work of making rocks. All the while this lime is heaping upon the sea-floor, there is a steady rain of mud upon it, some floating out from the rivers, some sent to the sea from the volcanoes. This mingles with the lime, and makes the clay which we find even in the finest limestones. If the lime gathers slowly, the clay will be perhaps the larger part of the rock; if the lime gathers fast, the clay will be a smaller part of the whole, so making anything from pure clay to pure limestone.

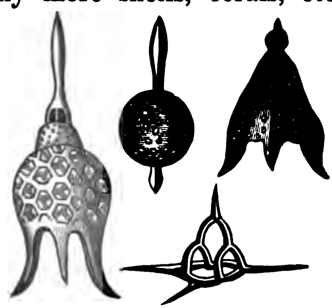


Fig. 20. Radiolaria.

Of all the rocks we see on the surface of the earth, the limestones form not less than one-sixth part; so the work of animal life, in building the earth's crust, is to be compared with the work of rivers or the sea-shores.

In many limestones we have great changes brought

about in their appearance by the action of heat: they are turned into marble. Marble is crystallized limestone. Heat, which often finds its way into rocks, and water that is always in them, cause this change. When it turns to marble, the limestone no longer shows the fossils we commonly see in it. They have all been dissolved and made over in the process of crystallizing.

With so much lime always going into the frames of animals, and at their death on to the sea-floor, the water of the oceans would soon become too poor in this substance to sustain the life it holds, but for the means that are arranged for its supply. This continuous supply is accomplished in the following way: Every drop of water that falls on the lands has a certain power of dissolving lime. When this water goes through the earth, it takes up from the decaying plants a certain amount of a gas they give off, called "carbonic dioxide." This is the gas used in making soda water, and is what gives the suffocating power to burning charcoal. The earth holds a great deal of it, as we can see in the case of wells that often fill with "bad air," which is this gas. Water eagerly sucks in this gas; and, when charged with it, can easily dissolve the hardest limestone, as it dissolves sugar or alum, and many other substances. We often see this lime gathering around the places where springs come out of the earth. Their water will often encrust anything put into it with a thick coating of lime. In this way the springs bring to the rivers a vast quantity of lime, which constantly restores to the sea the element that the animals fix in the limestone beds. As this lime is completely dissolved in the water, it does not settle to the bottom, but remains floating about in the sea, until it is taken out by the living creatures that require it to make their skeletons. In the course of ages, this lime,

now being laid down on the sea-floor, may be lifted up until it is above the level of the sea, where it in turn will be dissolved by the rain-water, and borne back to the deep.

We see at once how great the changes of the earth must be, to have lifted to our mountain tops these limestones that are now furnishing the lime that goes into the ocean; and we know that we may look forward to even as great changes in the time to come, when limestones now building on the sea-floor shall be raised to the tops of mountains that have not yet begun to form.

It is not until we come to study our soils that we know how much we owe to these little creatures that have separated the lime from the water. Wherever we find limestone rocks, there we have soils of rare fertility; for the reason that lime is a very essential thing to most of our crops, especially to grain, and because the same creatures that take out lime from the sea-water separate several other things that serve to enrich soils. The most important of these is phosphorus. This is the substance we know so well in lucifer matches; but it has a very great use when combined with lime, as it enters into the bones and bodies of all the higher animals; without it man could not live.

The fact is, the rain-water that passes through the soil takes out of it something of all the substances that the earth contains, and takes them to the sea; and the river waters are in this way constantly carrying a little of all our metals to the oceans. From the sea, the animals and seaweeds take these substances, and build them into rocks upon the sea-floor. Some of these rocks we see have been lifted upon the dry land, and these substances are again carried back by the rain-waters to the sea. So the particles move in an eternal circle from the sea-floor to the land, and thence back to the ocean.

LESSON V.

COAL.

THE next chapter that we shall study in the history of the rocks concerns coal. We have just seen that the ocean life, both plant and animal, is constantly doing a great work in the building of the rocks. In coal we have a like work done by plants upon the land. Looking at coal with the microscope, we find that it always consists of a black mass of vegetable matter, generally rather hard and shining. Further study shows us that there are various kinds of coal, which range all the way from soft peat, that we may find in any swamp, through lignite, that is like peat, a harder coal, to bituminous coal, which is soft, and burns with a long flame; or cannel coal, that is like it, only more flaming; then to anthracite, that is yet harder, has no flame, and is to be burned only with a strong draft; finally to plumbago, that is so changed that it can no longer be burned by any heat that we can readily apply to it.

To understand the history of these various kinds of coal, we must, for our first lesson, go to the forests and see what goes on there. Every plant is a contrivance for separating carbon from the air. The leaves of the trees and bushes gather this carbon from the air that sweeps by them, as the corals of the sea gather their food from the ocean. This carbon they find in the air in union with oxygen, forming carbonic acid gas. The oxygen they set free; the carbon they fix within their bodies. From the soil they take water, and a little of various substances, — potash, soda, lime, etc.; but, of these solid substances, they take only somewhere about the fiftieth part of their

weight. If we cut down a forest, and burn it, the part that goes away in flame and smoke came from the air; only the ashes came from the ground. When the trees die and fall to the ground, or when their leaves and branches fall, they do slowly what we do quickly by burning,—they give their carbon back to its union with oxygen, and in this form it again becomes invisible in the air. In an ordinary forest this process is always going on. The old trees, as well as their branches and leaves, which are constantly tumbling down, fall into the tangle of decaying matter that makes the forest-bed, and then rot, or, in fact, slowly burn, leaving only their ashes. Usually this goes on for ages. The living roots are below, the living trunks, branches, and leaves above, and between them this layer of decayed matter, where the dead parts are taken back into dust, or given to the air by decay. We know that the oldest forest-tree lives, perhaps, a thousand years; many of them take but four generations in two thousand years, so that some trees now living may be only the grand-children of those that lived when Christ was born. Yet we know enough of our forests, to say that, in many of them, time enough for five or ten thousand such generations to live and die has gone by since they began to be, yet the decayed forest-bed is at most only a foot or two thick.


Fig. 21. Rocks, Sub-soil, and Mould.

If all the trunks, leaves, and branches that have decayed in our ancient forests could have been heaped up unde-

cayed in a solid mass, we should have beds of wood thousands of feet thick where we now find only a few inches of black mould. But, in place of staying in the shape they have when they fall, all those parts of trees by decay give their carbon back to the air, whence it returns again and again to the plants.

It is interesting to consider that the same little particle of carbon now drifting about in the moving air, may at one time be fixed in the branches of a tropical palm, and then rest awhile in a lichen that grows nearer the pole than man has ever been. It may next grow close to the perpetual

Fig. 22. Growing Peat Swamp.

snow of the Alps, to pass, when death sets it free, to some seaweed rooted in the caverns beneath an ocean cliff.

This is the state of the dry forests. If there is a very wet forest-bed, into which the leaves and branches fall, they do not rot, but are preserved in the water. Wood will rot when it is partly wet, or at times wet, and again dry; but, if it be buried in water, it rots only in part, and not altogether. The most of its substance stays in it, becoming blackened and softened, as we see the vegetable matter of swamps, called "peat." In any swamp we can generally find a great depth of this black, half-decayed wood; but in these swamps our ordinary trees will not

grow; it is only small plants and mosses that flourish there. Yet, even these little plants can make very thick masses of peaty matter.

All the northern countries have very great and deep bogs of this kind. Sometimes the mass is ten, twenty, or thirty feet in thickness. This is the first stage of the making of a coal-bed: a mass of woody matter kept from complete decay by water, in which, however, it becomes black, softened, and matted together, until it is like a sponge. The next stage in making coal is brought about in this way. The level of the land sinks, or, what comes to

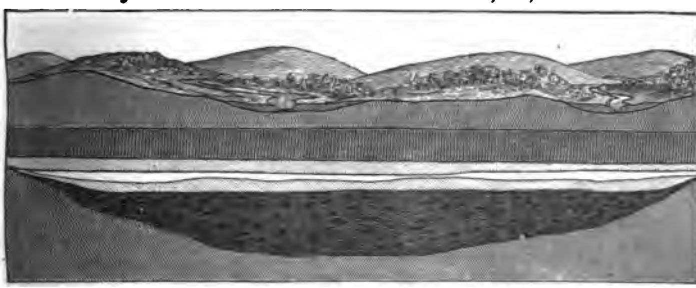


Fig. 23. Buried Peat Swamp in condition to become Coal.

the same thing, the sea rises until it covers this mass of peat. In this water there are currents that bring sand and mud from the shores, and bury the peat beneath a thick layer of these ground-up rocks. So buried, the peat is pressed together by the weight of the rocks above it, and gradually undergoes changes that bring it nearer and nearer to the state of coal. If the layer of beds laid down upon it is thick enough, it may become somewhat heated, which helps the chemical changes that need to go on. Coal has been artificially made by placing woody matter, like sawdust, under a great pressure, while it was somewhat, but not very much, heated. It has also

happened that a block of wood used for a socket of the shaft of a water-wheel, where it was exposed to a friction that could cause a little heat, was found, after a time, to have changed into a sort of coal.

To return to our buried peat bog. If it is sufficiently pressed and changed by the slow agents that time brings into action, its first shape is that of brown coal or lignite. This is rather more like a coal than peat; it burns with a livelier flame and is more solid. It is still of a rather brown than black color, and is never so heavy as coal. A further step of change produces the form known as *bituminous* coal. In this state the woody matter, still further changed, often breaks into blocks with shining faces. In the fire it partly melts like wax, and it burns with a long, yellowish-white flame. There are many varieties of it in this stage of its change, among which *cannel* or *candle* coal, so called because it burns with so long and steadfast a flame, is the most conspicuous. This cannel coal is made from the fine vegetable mud that is laid down on the bottoms of the lakes in the swamps. We can see it forming in such places at the present day. Cannel coal does not have the same appearance as the other bituminous coal. It breaks in a more irregular way, and can be polished like black marble.

Still further change, brought about by heat and pressure, makes what is called *anthracite* coal. This is much harder than the other sorts of coal, and burns with very little or no flame. This is because all the matter that can form gas has been driven out of the coal, leaving only the carbon, so that it is like coke or charcoal in its nature. We notice that anthracite is very hard to burn; it will not take fire unless in a good draft of air. Some varieties of it will not burn except in close stoves; sometimes we find

a part of the bed that cannot be burned at all. Still further on in the change, we come to the strange substance called *graphite* or *plumbago*. This is the soft material commonly known as *black lead*. It is used for making pencils, for which its softness and blackness fits it; but larger quantities are used for making what are called *crucibles*. These are pots for melting substances that require a very great heat, such as steel. Indeed, this graphite is able to stand a greater heat than fire-brick or any stone. Yet it is only carbon, exactly like that of coal, that, in some way unknown to us, but through the action of heat itself, has become incapable of being burned by any heat we can ordinarily apply to it.

In the coal field near Richmond, Va., we can see exactly how the heat can change coal. Above one of the coal beds there is a thin sheet of lava, which flowed there after the coal was formed. There is a layer of several feet of sandstone between the coal and the lava, yet the lava, having been as hot as molten iron, has so baked the coal that it is changed into a sort of anthracite. In certain places, where the lava did not reach, the coal is of the ordinary bituminous kind.

Thus, in this wonderful coal series, we pass from the living plant through a succession of changes, that first give us the various sorts of burnable coals, and finally this most peculiar substance, graphite.

This making of coal has been going on throughout all the great ages of the earth's history, but there were times when a great deal, and other times when very little, was made. In that age of the earth's history known as the carboniferous or coal period, because of the extensive coal beds that were then deposited, the air of the earth was probably damper than now, and the winter's cold was not

enough to kill delicate plants, even close to the poles. Then the forests had none of our common trees, such as oaks, beeches, maples; none of the plants we see in our woods to-day existed, but in their place a quantity of others, like our club mosses and our ferns, but growing to the size of small trees. These plants could grow with their roots all the time in the water, which our modern trees, with the exception of the swamp cypress and mangroves, cannot do. Besides this, their tangled roots and close-set stems made a sponge that held water; and so the swamps of the coal period grew even on hillsides, when they were not steep, as well as on plains. They made peaty matter that would turn into coal when buried. As if to make everything as it should be for the formation of coal, the lands or the seas in those days were very unsteady. The level of the oceans was often changed, so that a great part of the continents was often lifted above and buried beneath the seas. Thus to these beds we look for the greater part of the coal that is burned in Europe and America.

If we examine a coal seam, we can always find the bed of earth in which the plants grew; above that the bed of coal; and, above all, the beds formed upon the swamp sunk beneath the water. These beds are arranged one above the other, so that in some countries there are as many as a hundred coal-beds in a thickness of less than five thousand feet of strata.

Next to the present soil of the earth, these old buried swamps of the earth are of all the earth's resources the most important for man's welfare. While the present surfaces give him food, those old buried lands give him heat and power, which he turns into infinitely varied uses.

Let us consider a moment what this heat and power come from. When plants grow, they do so because they

are warmed and lighted by the sun that shines upon them and the air that wraps them round. This force of the sunshine they store up in the substances composing their bodies; when we burn their wood, or it decays in the mould at their feet, this force is given back at once to the air. When the woody matter is buried in the coal-bed, the force is kept from passing back to the air — is stored up in a way to be useful to man. When we burn coal, then we turn the buried sun power of ancient times to our present uses. We warm ourselves with it; we make it turn our mills; and, in this manner, we have our profit out of the light and heat of days so far away that we cannot imagine the years that have elapsed since their light has ceased to shine and their life to exist.

It is only in the modern times of man's history that he has used coal. Neither the Greeks nor Romans nor Hebrews knew anything of it. Its use began in England not more than six hundred years ago, and its great profit was first found in the use of the steam engine. Now, the chance of future wealth of nations depends upon the amount of coal they have beneath the ground in their territories. Although there is a little coal in most countries, the really large and useful supplies seem to be limited to northern Europe, where England has the best, to North America, which is ten times richer than Europe, to China and Australia. The best that is known is in North America, though the largest fields are in China. South America and Africa appear to have but little. The countries about the Mediterranean, once the richest and most powerful in the world, cannot regain their ancient place among nations because they have in their lands scarcely any store of this buried sunshine.

Thus we see how the most remote events of our earth's

history may come to affect the well-being of man, determining the strength of peoples and the seats of national power. The fact that the English-speaking peoples hold the best supplies of coal, makes it certain that their states are to have the commercial empire of the earth.

Besides the work of storing up coal, plants and animals, when buried in the rocks, may furnish by their slow decay the substance called *petroleum*. This substance is formed by a slow chemical change in the bodies of creatures buried in the rocks. These changes then form not only petroleum but a great deal of gas, so that, when we bore a hole into the rocks where it has formed, the gas will drive the oil out with great force. Most all our rocks containing fossil animals or plants make some of this oil, but it is generally pressed out by the gas as fast as it forms; but when there is a continuous sheet of a very dense, impervious rock, such as clay slate, above them, the oil is retained until it accumulates in a large quantity, so that a well may throw out two or three thousand barrels a day whenever the rock in which the oil lies is bored into.

Many parts of the world have furnished enough of this coal oil to make its gathering profitable. For centuries it has been gathered in India and Japan by means of common wells. But the great source of supply is in western Pennsylvania and West Virginia; and there, small bored wells, a few inches in diameter, are used to get to the buried store. When the oil is struck, it often blows the boring-rod to the height of several hundred feet into the air; sometimes this fountain catches fire and strews destruction about it.

Besides these forms of buried force, laid down in the earth by animal and plant life, there are many deposits of

clay shale that are full of organic matter, from which coal oil can be distilled; but, as it is not so cheap as that from the flowing wells, they have not been used since the flowing wells were found. One of these beds of clay shale, in the valley of the Ohio, extends over a region over one hundred thousand square miles in area, and averages over one hundred feet thick. As it contains about one-seventh of its bulk of substances that can be distilled into coal oil, it is equal to a lake of oil three times as large as Lake Superior, having the depth of about fifteen feet.

In these oil-bearing clay shales there is a store of heat and light-giving materials that will serve the uses of man after he has used up all the coal of the world.

CHAPTER III.

THE WORK OF WATER AND AIR.

LESSON I.

THE AIR.

WE have already beheld some of those things of the earth that we can grasp with our hands and examine in various other tangible ways, but we now turn to that unseen kingdom of the air, which more or less affects all that occurs upon the surface of the earth. The air, though invisible, is much like the watery ocean; it is made up of one constant fluid or gas called *nitrogen*, in which are mingled smaller quantities of certain other gases, of which the most important are oxygen, the vapor of water, and carbonic dioxide, or the gas that oxygen and carbon commonly make when they unite. Because the air lets the light freely through its substance, we do not easily see it; but when we look at distant mountains in the clear daylight, they usually look blue, and this sky or mountain blue is the color of air. This great ocean of the air wraps the whole world about. It is densest at the surface, and grows thinner as we rise above the earth, until, at about fifty miles of height, it is so thin that it cannot well be called air at all; but there is no definite upper limit to the air, — it grows thinner and thinner, until it become space or ether. There are good reasons for believing that this air is composed of innumer-

ably small particles, all dancing to and fro with a great speed. These atoms are so small that if we should take the smallest bit we can see, its bulk would contain millions of these little dancing bodies. They move so swiftly that they would soon work away from the earth, but that they are all held down to the surface by its attraction. Between these atoms there is supposed to lie the yet smaller grains of the matter called *ether*, which is not attracted by the earth, and so is no thicker at the earth's surface than in the furthest spaces between the stars. This maze of dancing particles constitutes our air. It would be interesting to trace all that is known of their strange ways, for, though they are invisible, we know much about them; but we are to look now only at the manner in which the air as a whole behaves.

First, we see that the particles of air are very easily moved. Swing the hand to and fro, and we perceive that we can just feel them, they slip so easily by. When moved by a strong wind, we feel them press upon us. Next, we notice that when heated this air rises. Look at the column of smoke over a chimney: it goes up because it is heated. Make a little smoke over a stove, and see how it flies to the ceiling. So we perceive that a little difference in heat sets the air moving upwards. Blow the smoke against a cold window-pane, and see how it falls to the floor. So we know the cold sends the air downwards. This air can take a great deal of water into its tangle of atoms. Moisten the finger, and move it quickly to and fro, and we feel the water evaporate, and in a few minutes it is dry; the water, in the form of vapor, has slipped into the air, where it is unseen. Watch the rain falling, and we see this vapor of water, evaporated from sea and land, turning back into the liquid state again.

On these properties of the air, its fashion of moving up with heat and down with cold, and of taking other gases into its mass, depends, in the main, all the wonderful work it has to do on the earth.

When the sun rises high in the heavens on a summer noonday, we see it warms the air. We can imagine that under the equator, where the sun is nearly always overhead, the heat is great; while at the poles, where it never gets half-way up the dome of the sky, and for much of the year never rises, it is very cold. This greater heat at the equator causes the whole air that lies in that region to rise up from the surface. To take its place, the less-heated air, from regions nearer the poles, flows down towards the equator. This causes a down-draft into the far northern and southern regions; and, to replace the descending air, there is a current far up in the atmosphere, blowing from equator towards the poles. This is shown in the figure.

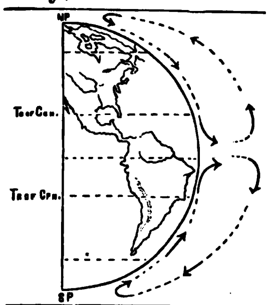


Fig. 24. Diagram of Air Currents.

If the earth were all land or all water, this would be the only general movement of the air; but, as its surface is a great ocean, flecked over with many lands, this great current, from poles to equator and from equator to poles, is broken up, except on the great seas. Under the sun, the land heats more rapidly than the sea, and so there is generally an up-draft made over all the land when the sun is high in the heavens, and the land warmer than the sea; while a down-draft takes place over the lands if they are colder than the sea. In this manner, and by many other

differences of a lesser kind, the winds are made variable, so that we cannot reckon on their movements except in certain parts of the earth. But the important fact about the air is that it is always in motion; for such a thing as a perfectly still air is not known in the world. Ceaseless motion possesses it everywhere and at all times. This fits the air for the important duty of carrying water from the seas to the lands. The heat of the sun slips as easily through the air as its light, and, falling on the seas, so warms them that they give a good deal of vapor to the air; this, by the motion of the air currents, is borne off over the lands, where it falls in the shape of rain; so that the first duty of the air is that of a rain carrier, bringing the water back from the ocean to the land as fast as it flows out through the rivers. When we look on a stream like the Mississippi or the Amazon, its mighty tide rushing into the ocean, we may see in the heavens above the channel through which the winds are constantly carrying the same waters, first up from the sea to the height of several miles, then in the sailing clouds, along through the air for, it may be, thousands of miles, to the lands where it falls as rain. This eternal circle of the waters has been traversed thousands of times by every atom of water in the world. On this endless journey of the waters depends the whole system of feeding the life of the sea and land. The land life could not live without the rain, and the sea life would not be able to live without the rivers bringing back to the ocean the things that are stored in the rocks of the land. So the life of all the world is kept in being by this circuit of the waters.

The next important work of the air is to furnish a blanket to keep out the outer cold. Life, as we know, cannot exist when water is constantly frozen. Only the

birds and mammals (animals that suckle their young) can live at all in a temperature below 32° F.; but ten miles above the earth there is, and always has been, a cold of below zero. But for the air, this cold would descend upon and stay on the earth. There would be no night even in summer and under the equator, where the temperature would not fall to zero or below it. The air protects the earth in this way. The heat that falls from the sun goes through the air with ease, as it does through a pane of glass; but, when it warms the earth, this heat it gives to the surface cannot go back as easily, especially if the air have some vapor of water in it, as it always has. This heat that has fallen in the day will not be able to go back into space during the night, but is held upon the earth. Thus the air is a trap into which it easily enters, but escapes with difficulty. This work of blanketing the earth against the outer cold is one of the most important effects of the air.

Yet another, and one more important work of the air, is to supply oxygen to animals and carbon to plants. Both these gases are borne on the air, but in different proportions. About one-fifth the whole weight of the air is oxygen, but only about one two-hundredth is carbonic dioxide, or gaseous carbon. As the air goes by animals and plants, they take what they need of these gases. The animal takes the oxygen by its breathing organs, and gives back to the air carbonic dioxide. The plant takes this carbon and oxygen combined, separates the two, and gives back the oxygen to be carried until it is needed by animals. Even in the sea, every plant gets its carbon from this gas, which is mingled in the water; and every animal breathes by taking the air that is always similarly mingled in the oceans. If we boil some water, and then put a

fish or any other water animal in it, it will die; for boiling drives out the air that is in water. If we pour the boiled water from one vessel to another for a few times, the air will be again entangled in it, and the creatures will be able to breathe.

Thus we see that the universal wrap of air that the earth has about it serves as a great medium of exchange in the work of the world. Into it, after death, the animals and plants cast the store of materials which they took from it while alive. If they decay on the surface of the earth, they quickly give it back; if they are buried as fossils, these substances taken from the air may be converted to coal or petroleum; and only after a long time return to the great storehouse of the air, to be ready for the use of other living things.

In this way, from the ancient ages, the air has always been ready to lend the things that make up the largest part of animals and plants, taking them back in time for the use of other creatures. As the great agent of transportation, the water carrier, the heat carrier that brings the sinews of life to every creature of the land, the air has given to everything that has ever lived the first condition of its existence.

We have only touched on the principal duties of the air, but we have seen enough to show us that this scarcely visible element, that seems to be the merest thing of chance, has most important duties in the work of the world, and does them with wonderful perfection.

LESSON II.

THE WORK OF WATER.

The greater ocean of the air wraps the whole world about. The other great fluid, water, covers only about three-quarters of the surface. Though the oceans are smaller in size and less deep than the air, they weigh more than all the atmosphere. At most, air presses with a weight of only fourteen pounds to the square inch; but in the deeper seas the water presses with a weight of halt as many tons on an equal surface. These two mobile parts of the earth, the gaseous air and the fluid water, rule the earth's surface. Almost everything that happens here is due in some degree to their work.

Let us consider how water does its work. We have already seen a good part of this work in tracing the history of pebbles, sand, mud, etc., so what we have now to do is to show the work done by water that does not appear in the history of those things.

Foremost of all its work, we must place the power of water to dissolve all things. Some it takes up easily, as, for instance, all the different sorts of salt; but all the other things of the world, even the least soluble metals, yield to the water something, which it conveys to the seas. What water cannot do of itself alone in the way of dissolving, it manages to effect when it gets charged with carbonic dioxide gas, as it does in the decaying mould of our forests and elsewhere. In one way and another, it gets even such metals as gold and silver into solution, though in small quantities. To this power that waters have of dissolving all substances we owe the pos-

sibility of animal and vegetable life. Plants and animals grow and live through their circulations. Currents of water in the shape of sap or blood carry numerous substances through their forms, which are built into their frames. The same currents of water bear away the waste or dead parts of the living structure back into the outer world.

In the life of the whole earth, as in the life of an animal or a plant, water is the great means of carriage. By its motion food is brought to the creatures of the sea, and the matter thrown out by volcanoes, or brought to the sea by the rivers, is carried to the place where it is to be built into new strata on the sea-floor.

In its large work of carriage, water is charged with the conveying of heat from one region to another. The currents of the oceans take the hot water from the tropics to the poles, and the cold water of the poles to the tropics; and thus make the earth's climate far more uniform than it would otherwise be. The Gulf Stream, that great current which flows northward in the Atlantic from the Gulf of Mexico, carries more warmth to the Arctic regions than comes to them from the sun. This circulation of water in the seas is not unlike the movement of the blood in our own bodies. As blood carries food and warmth to all the bodily parts, so this system of the waters in the ocean streams, clouds, and rivers, nourishes and warms the whole life of the earth.

There are many of these great streams of the ocean flowing in circling currents, warm from the tropical regions towards the poles, and cold from the polar regions to the tropics. But for the great stream of heat they carry from near the equator, the tropical countries would be too hot for man to live in, and all northern Europe and

the most of the United States would be so cold that they would be of little use to man.

One of the great works of the sea is in building the rocks that afterward, lifted above its surface, form the continents. This work is constantly going on all over its bottom. When the great ocean currents sweep near the land, they take up a large part of the mud brought down by the rivers, and bear it far out to the ocean depths, where it falls to the bottom, and is built into rocks.

All over the ocean bottom a host of fixed animals are living which are fed by the water and the things the water brings to them; dying, the bodies of these animals are built into the rocks. Floating wood and seaweed rot and

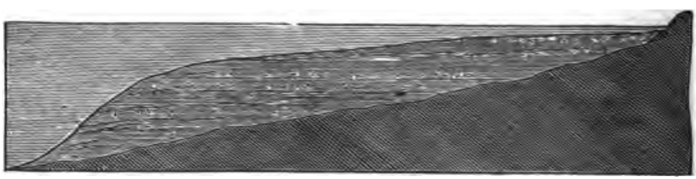


Fig. 25.
Coast Shelf made by the Tide.

become water-logged; then sink to the bottom to mingle with the mud and the remains of animals, the whole being built into rocks.

Along the shore the waves and the tide are continually taking a part of the mud out into the sea, and making new stratified rocks of them. All along the shores of the continents there is a submarine shelf of this waste that the tide and waves have borne away, which makes a shallow belt of waters near the shore. Along the eastern shore of the United States this shelf has this shape.

Thus, while the sea is continually destroying the land by its waves and tides, or by the water it sends as rain, it is always building them back into rocks again, — rocks which may in time, perhaps, be lifted into new lands.

LESSON III.

VEINS.

If we look closely at any very old and much changed rocks, we shall find that they have been divided by gashes that cross the bedding, and that these gashes are filled with various stones, sometimes containing metals, as gold, silver, copper, etc. It is from these veins that come our supplies of all the metals used in our arts except iron, so they are of a practical as well as a scientific interest.

The first question we ask ourselves is how the crevices that hold the veins came to be formed, and then how the minerals that fill them came into their places.

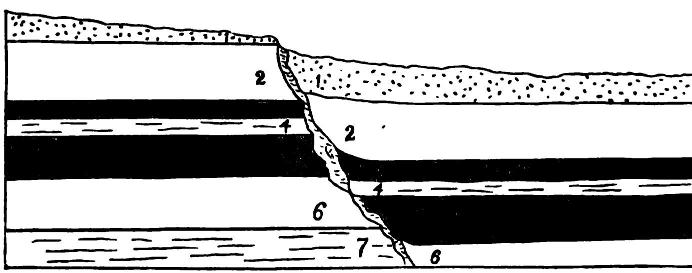


Fig. 26. Ordinary Fault; numbers show beds originally continuous.

Veins are formed in crevices that open in the rocks. They are due to different causes. Sometimes they are the result of a shrinking of the rocks, something like that which takes place in drying clay; at other times the rocks having been pushed from the sides, were forced to break into large fragments, and pieces slipped over each other, as in Fig. 27.

When these breaks are formed, they leave an opening in

the rocks which is never very wide but may be very deep. This crevice is sometimes ten thousand feet or more from top to bottom, and not more than a few feet from side to side. Some parts of its walls generally rest against each other, there being at times only a rambling crevice that a mouse could hardly creep through.

We have now to notice again that some of the sea-water is prisoned in the rocks when they are made, and so is often buried to great depths beneath the surface. When deeply buried, this water is very much heated by the heat that exists in the depths of the earth. When such a rent is made in the rocks, these deep waters find a path to the surface. It also happens that some of the rain-water that falls on the earth often finds its way to great depths. When in the depths, it becomes heated, and gets thereby great power of dissolving various substances. We all know that water will dissolve more of all the substances that it takes into solution when hot than when cold. After a time this water is urged towards the surface, and generally creeps up along with some of the water that was buried in the rocks when they were laid down on the sea-floor.

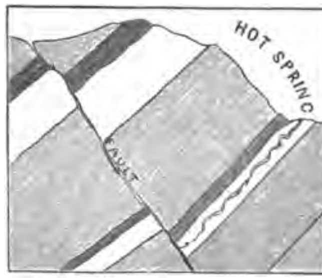


Fig. 27. Diagram of a Hot Spring.

This mixture of rain and sea-water, by means of its salt, its high heat, and the presence in it of various gases, dissolves a portion of all the substances it touches; and so, when it starts again for the surface, it has a great load of various minerals in its keeping. The easiest way for it to get to the surface is through just such rifts of the

rock as have been described. When it starts upward, it is at a heat that may be very much above the boiling point of water. In a shallow open vessel, water boils at the heat of 212° F., but if we made the sides of the kettle a mile high, we should have to raise the heat of the water at the bottom to a high point before the water would boil. In many cases, when the water starts up towards the surface, it has more than a mile of water above it, and so it can have a very high temperature, — a thousand degrees or more. Water at the temperature of a thousand degrees cuts many stones like an acid, and can hold a wonderful amount of matter in solution. As it creeps up toward the surface, it grows cooler, and has to part with a portion of its burden. This is done by laying down certain minerals or metals on the sides of the crack through which it flows. After a time, the waters becoming cooler, another substance may be laid down, and so on, until the way for the water is quite blocked up. In this way the vein comes to appear in a cross-cutting like the figure.

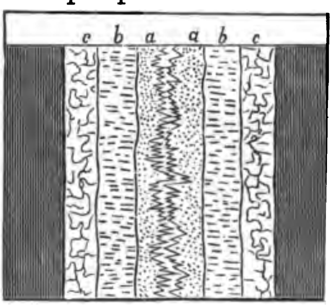


Fig. 28. Section through a Vein.

The water, when it comes out on the ground level, appears as a hot spring. There are many thousands of these now in the world, and each may be making a lode or vein like that shown in the figure. It is only a part of the veins that are made that have any metallic matter in them. In many cases the water may not have been hot enough to dissolve the metals; or there may not have been any in the rocks through which it passed. Generally, however, we shall find a small quantity of metals in any vein, but it

is not likely to be great enough to pay the miner for his labor in getting it out. We find, when we study hot springs, ample proof that this explanation of the process by which veins are made is true; gold and other metals have been found in their waters, and they deposit about their mouths just such stones as we often find in veins; besides these, very hot springs are oftenest found in the regions which are rich in valuable mineral deposits. The great Comstock Lode, which has produced more silver than any other in North America, and more gold than any other mine in the world, is still the pathway of hot springs. The miners are constantly fighting water hot enough to scald the skin.

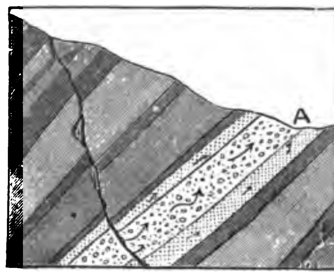


Fig. 29.
Sandstone becoming Mineralized.

There are other ways in which deposits somewhat like veins are formed. Sometimes the hot water from below, trying to find its way to the surface, creeps upward through a steep sloping bed of rock which is porous enough to allow the water to crawl through it.

In Fig. 29 the bed A is supposed to be a sandstone or a pudding stone through which the water can rise slowly to the surface; the metals will then be gathered in the little spaces between the stones or sand-grains as it is in a vein. Sometimes, also, the waters of hot springs, as

Fig. 30. **Hot Spring Caverns.**

they climb towards the surface, eat out caves in the rocks, especially if they be limestones; in the eourse of time, when the waters are less hot, they may fill these caverns with mineral deposits, such as gold and silver ores. Some very valuable deposits of this sort have been found in the Rocky Mountains.

In the countries where there are mineral veins, but no hot springs at present, we find proof that the veins were formed a long time ago, giving time for the movement of hot waters to cease.

The powers of destruction go always hand in hand with the powers of construction. These veins are not long formed

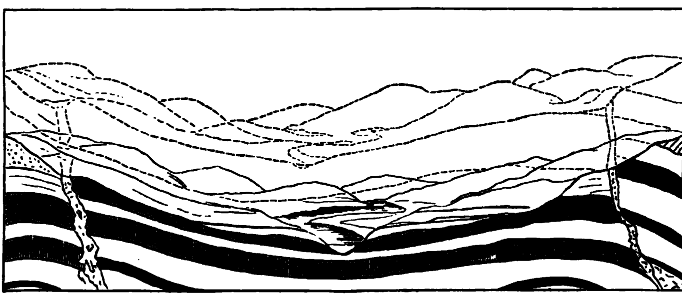


Fig. 31. Wearing down of Land; dotted lines show ancient surface.

before they begin to wear away under the action of rain, frost, or glaciers. If the veins hold gold or platinum, these metals being heavy and hard to dissolve or rust, they are often found gathered in the beds of the streams mixed with the gravel and sand; but all the other metals are easily rusted, *i.e.*, combined with oxygen, in which state they may be dissolved in the water and washed away to the sea. Even the gold and platinum gradually go into the water, and are borne to the sea; once in the sea-water they stay there for a long time. When the sea-water evaporates, these metals cannot rise up to the clouds with it; the only

way out of the water is through the bodies of animals and plants. These creatures each take a little of the many substances in the sea-water, and when they die and decay, leave this little locked up in the mud on the sea-floor into which their remains pass. This mud is slowly changed to rock, and in time may be lifted into the air again. These rocks have veins formed in them again; the metals may be once more gathered into the crevices, and again worn away by the rivers and carried to the sea.

This is another of the circles of change through which water leads the things of the earth. And here, as in many others, life has a share in the work. Every particle of gold we see may have been several times through this slow journey from the sea-water to the living being; thence to the sea mud; thence, in turn, to compacted stone; then to the vein; and, finally, by way of the mountain streams, back to the sea.

Only a very small part of the gold, silver, tin, lead, or other metals that get into the rocks finds its way into veins; by far the larger part is never so gathered together in veins, but stays in the scattered form in the rocks, and goes back to the sea when they are worn away.

There is another way in which these fractures are sometimes filled. In place of various mineral substances deposited by water, the crevice becomes charged with molten rock,—lava, as it is commonly called,—which is crowded into the space. When filled with this substance, its forms are no longer known as veins; they are termed *trap dykes.* It often happens that we find a trap dyke and a vein close together; but in the lava itself we rarely find any valuable ores in a shape to be mined. It is not quite certain just how these trap dykes are formed, but this is probably their history. When the crevice forms, by the breaking apart

of the rocks, it may extend down into the earth to a greater or less depth. If it go very deep, it may find its way to a part where the rock is heated so hot that it can flow like melted lead or iron. This lava is squeezed up into the crack. The pressure that drives it up probably comes from the steam that all the deep rocks seem to hold. This steam is held in by the rocks that lie above it, which close it in like the sheet iron of a steam-boiler. As soon as a crevice is made above this steam, it drives the molten rock up into it. Generally these trap dykes are much wider than most mineral veins. They may also run

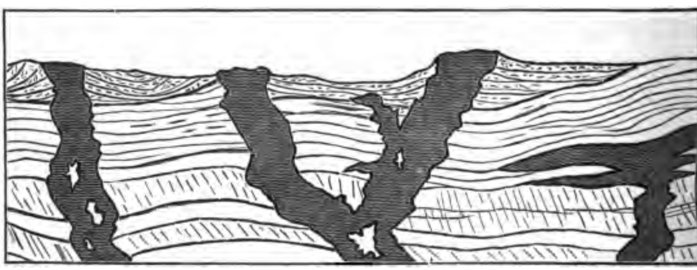


Fig. 32. Some Forms of Dykes.

deeper into the crust of the earth. In some regions they are exceedingly plentiful, there being one every few feet of distance as we go across the surface. We generally can see that the dyke stone has been very much heated, for it has baked the walls of the crevices. At other times we find pieces of stone torn from the sides of the crevice, with sharp edges in the trap; showing that it was not hot enough to melt them.

These dykes come into close relation with the volcanic lavas, the only important difference being that the volcanic lavas are thrown out into the open air, while these traps were formed far beneath the surface, and are therefore gen-

erally much the most solid. We shall see more of these lavas when we come to study their behavior in volcanoes. It is only because they are often connected with mineral veins that they are touched upon here.

We have now seen that underground water often makes deposits of precious metals in crevices. We will now turn to the action of water in its rarer but even more interesting form of working, when it makes caves such as the Mammoth Cave in Kentucky.

LESSON IV.

COURSE OF WATER UNDERGROUND.

THE greater part of the work done by water is done above the ground; but there are certain peculiar effects it has, when it works below the surface, that have much interest for us. Some of these we have noticed in the history of mineral veins. There are, however, many other peculiar results that are of a very different character.

When water falls as rain, a part of it flows at once away to the streams, and a part penetrates into the earth. That which goes below the surface creeps slowly through the earth until it is either sucked up by the plants or escapes into the springs. This underground water that is going towards the springs generally cuts for itself little imperfect channels, by dissolving away the soil so as to make a natural drain, which we imitate when we put pipes under a field for drainage. But these springs that do not have their channels below the level of the soil are always very small, and last only during wet weather. When we find a spring with a strong stream of water, we may be sure that it comes out of the earth from below the level of the soil after a journey through the underlying rock. The question arises, how does it manage to make a passage through this rock? These rock passages of the underground waters are sometimes among the most wonderful of the works that water makes. If the rock be one that water cannot easily dissolve, such as sandstone, claystone, pudding stone, granite, etc., the only chance for water to make springs is to get deep into it through some rift or break in the mass of rock. These are not often found.

The result is, that such springs are rarely found in regions underlaid by rocks of this sort. The most of the surface of New England, for instance, is almost destitute of good springs because it is generally underlaid by very hard rocks. When, however, the underlying rock is limestone, we generally have very many large rock springs that carve out for themselves great underground channels called *caverns*. These caverns are of very different sizes, sometimes being small tube-like openings that are hardly large enough for the swollen waters in times of rain. These occur when the limestone rocks are bedded with strata,

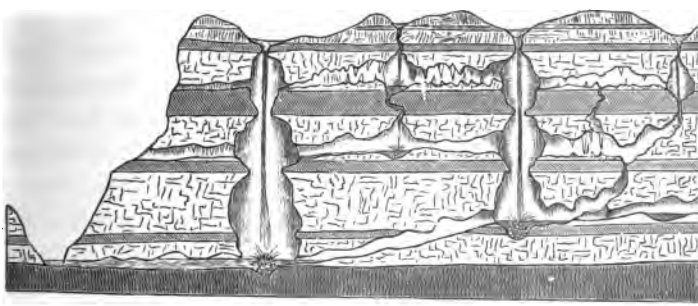


Fig. 33. Section through Caverns in Limestone Rocks.

like claystones between, that are not to be dissolved by the water. When, however, the beds of limestone are thick, and without these clay partings, the caverns may become very large indeed.

Perhaps the largest of these limestone caves are found in Kentucky, where there is a region containing about eight thousand square miles of country that is completely honeycombed with them. Some of these, such as the Mammoth Cave, are so vast that we may walk for days through passages that are often thirty feet or more high

and fifty feet wide. Underground rivers and waterfalls, chambers beautifully ornamented with wonderful stalactites and stalagmites, and a great number of animals that live in the cavern and nowhere else, make these chambers quite an underground world, where everything differs from the daylight region.

The way these caverns are formed can easily be seen by studying what is now going on in the country where they occur. This Kentucky cavern district lies in an elevated, level region, where the rocks have never been tilted about, but stay in much the same position as that in which they were made on the sea-floors, before the coal time. When we journey over this country, we see that only the large streams appear at the surface of the ground. These flow in deep gorges, with steep cliffs on either side. The smaller streams do not flow on the surface. They come into the main rivers through cavern mouths, that often lie below the level of the water, along these greater streams.

The surface of the country between these rivers has no valleys in it, such as have the streams in most parts of the earth, but is arranged in circular shallow pits, called *sink holes*, such as are shown in figure. Of these there are often several dozen in a square mile of fields. All the water that runs off the surface in a rain goes into these sink holes, and flows down into the earth through a small, ragged tube that descends from the centre of the pit. We can often hear it in times of heavy rain running down into the depths of the earth. Some of these sink holes have large openings, so that a brave explorer can be lowered down into the underground course of the water. In this way, we can see the whole course of the cavern making. The sink hole is shaped as in the figure, which shows a sink hole and the lower chambers cut in

the thick beds of the limestone, which may be as much as three hundred feet in height, from the narrow throat at the top to the base. The entrance from the open air is generally very narrow, but with various irregularities. The opening widens until it is sometimes as much as fifty feet from wall to wall. Whenever there is a strong shelf of rock, there are generally level passages leading off into the distance towards the lower mouth of the cave. We may pass several of these in the descent. When we arrive at the bottom, we find a pit generally full of water, and by its side another horizontal passage leading off into the darkness.

In the bottom of this vertical chamber or dome, if we look closely, we see many bits of flint and other hard stones. They are not a very striking feature of the cavern, but they are the key to a part of its work. We must now conceive what happens in wet weather, when down this deep shaft the water rushes with very great force. These hard stones are then driven like miner's drills against the rock, and they speedily cut up the soft limestone. The lime is easily carried away by the stream through the side passage. The bits of flint themselves are found in the limestone rock. We can often see them sticking out of the walls, and the Indians were in the habit of coming to these caves to get such flints for their arrow-heads.

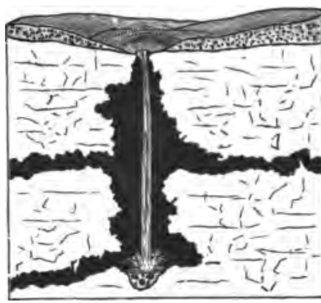


Fig. 34. Dome of Cave.

Entering into the side galleries that open out of this "dome," we find that they lead off horizontally for great

distances; sometimes, as in the great avenues of the Mammoth Cave, we can walk through a passage as large as the aisle of a cathedral for four or five miles. Each of these side passages or galleries gave a way for the water out to the air, at the time when the dome had not cut deeper than down to the level of the floor of the particular gallery. The "domes" of these caverns are sometimes wonderfully grand. The walls are sculptured by water into fantastic likenesses of columns. When lighted with bright fires, it is hard to believe that we are not looking upon some supernatural work. The galleries, if less grand,

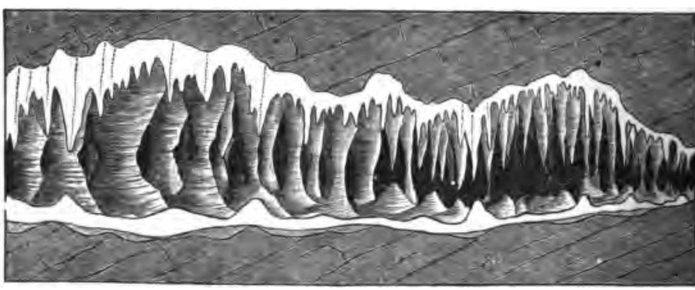


Fig. 35. Part of Gallery nearly filled by Stalactites.

are more beautiful, and in them are found the finest specimens of those stalactites that are the chief ornament of these underground chambers.

These singular structures are of the most varied forms. Sometimes they are like flowers, clustering over the ceilings, and shining in the light of the torches; again, they are like the trunks of trees growing from the floor to the ceiling. Sometimes they appear like fountains; again, like sculptured monuments; but always decorated with strange tracery. If we search the cavern, we can find how these singular forms are made. Choosing a place where the roof of the cave is low, we can see that the water slowly trickles

through the ceiling, and falls, drop by drop, to the floor. This water comes slowly, each drop glistens awhile on the ceiling before it falls; during this time, when it is still, some of the carbonic dioxide gas escapes from it, and a part of the lime it holds is laid down on the ceiling. We can often see the very beginnings of a little hanging cone formed in this way. Gradually this cone grows until it hangs half way to the floor of the cave. When the drops fall, they splash out and evaporate in the dry air of the cave, leaving the rest of their lime in a little heap on the floor. This heap grows upwards towards the cone that builds down from the ceiling, until at length they are united. Now the drops no longer fall, but creep down the sides of the unbroken column, evaporating as they go, leaving their lime on its sides. And so the mass of stalactites constantly grows larger and larger. In time they fill the whole gallery; and in this way, after centuries, this passage of the cavern is destroyed. It is only when the ceiling of the cave is so close that water cannot trickle through it, that this process does not in course of time fill the whole space with stalactite.

The bottom of these caves can never be lower than the neighboring river, where the underground waters are discharged. As the river cuts deeper into the rocks that form its bed, the domes work further down into the rock, and new and lower galleries are formed.

While this underground work is going on, the decay of the surface is going on also; so that the uppermost galleries are slowly destroyed. Their roofs grow thin and fall in, so that they are opened to the day. Now and then, parts of their ceilings hold on for a long time, and in this shape are called natural bridges. All these natural bridges are the remains of great caverns. Some of the

finest specimens known are found in Carter County, Kentucky, and Rockbridge County, Virginia. At this stage in the decay of a cavern, the ruins look like the figure.

This wearing down of the caverns goes on for ages, so that over the place where the caves now are we may believe there have been many other caves, perhaps hundreds of feet in the air, where the earth once was, in the ages before the level of the ground was worn down to its present position.

Fig. 36. Natural Bridge.

To the students of nature these caverns are full of interest. First, they show to them the wonderful dissolving power of water when it runs through limestone rocks. They also contain many strange forms of animal life. Some of the outside animals use these caves as places of shelter. The bears that sleep through the winter often resort to caves for shelter; and, during the winter season, great numbers of bats are found in them. These bats are often to be seen hanging from the ceilings in great bunches, one grasping on the other, the topmost holding to the roof. They are asleep, and for all the winter time hang motionless, as if dead. When the spring time comes, though the temperature of the air does not change in the least, they know in some way that their

Fig. 37. Bats in Cave.

time for waking has come; their stagnant blood begins again to flow freely, the heat of their bodies returns, and forth they go to the open air again.

Besides the many creatures that use the caverns as a place of occasional resort for shelter, there are many animals that live their whole lives in this perpetual darkness. There are certain fishes which are found there and nowhere else; these species have lost not only their sight, but the very machinery of vision. Their eyes have disappeared, and a very delicate sense of touch in the parts about the head takes the place of the sight-sense. The same thing occurs in many forms of insects and crayfishes.

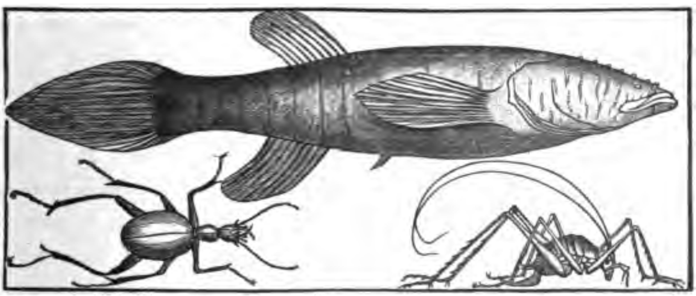


Fig. 38. Cavern Insects and Blind Fish.

Their eyes also disappear, and their feelers become lengthened. These facts are not only curious, but they seem to show the close relation between the conditions in which an animal lives and the form and functions of its body. In this age, when naturalists are trying to find out the laws that have fixed the shapes and organs of living beings, these facts, revealed in the underground world, are of the utmost importance to science.

There are many other phenomena connected with caverns. We can notice only a few of them. If on a summer day we approach the mouth of a cave that opens low

down on the cliffs near the stream, we perceive, even at some distance from the cavern's mouth, a strong wind that rushes out of the shadowy opening. This wind is often so strong that it makes the ferns and bushes about the mouth sway to and fro. It is so cold that it sends a chill through us as we step into it from the heated summer air. The hotter the outer air, the stronger this blast from the cavern. In the last part of the night, when the outer air is cooler, the current becomes less strong. In winter it turns, and we then find a stream of air entering the cavern, that runs as briskly inward on cold days as it did outward in hot weather. From the sink holes above the cavern, which connect with the domes, we feel the air pouring out in a strong stream. When the day is very cold, we see this warmer air of the cavern, which is somewhat moist, condensed in the cold outer air, so that it looks like steam. The reason for this movement is plain. In the summer time, the air in the cavern is much colder than that in the open, and, being colder, is much heavier; it therefore flows out at the lowest opening of the cave. There is then a current of warm air setting down through the sink holes into the cavern. The cold rocks there soon cool it, so that the blast from the mouth of the cavern is sustained. In the winter time, the cavern air is much warmer, and therefore lighter, than the open air; and so the cavern gives a current upward through the sink holes, while it draws in through the mouth. This is the same law that rules the great circulation of the air from the equator to the poles. So vast are the interiors of these greater caverns, such as the Mammoth Cave, that, despite these constant currents into it, the temperature constantly remains the same, there hardly ever being a degree of difference between winter and summer.

It may be interesting to the student to know some facts concerning the use of these caverns by man. The Indians evidently travelled through most of them, for we find their footprints everywhere. The soft sand that fills many of the passages of these caves will preserve a footprint unchanged for many centuries, and so we can find the tracks of a people that vanished from this land a century ago, the print of the moccasin looking so fresh that it might have been made but an hour. We also find there torches which they made by filling hollow canes with grease, an arrangement that makes a very good torch. It is evident that some of these caves were used in times of war as places of retreat, for some of the remote chambers, that a stranger can hardly find his way to, were evidently lived in for a considerable time. In one or two cases the bodies of Indians have been found who had evidently wandered away, while seeking to find the way out, and were lost in the labyrinth of passages. These bodies have not decayed, but have dried like mummies in the air. The Indians also used these caves as places of burial. Sometimes the bodies were only thrown in through the sink holes; in this case they were probably those of enemies slain on some battle-field. At other places we find the bodies carefully buried, with all their trinkets and tools about them, with the hope that those things might serve the dead in the long hereafter of plentiful hunting and war that their friends hoped for them.

The white men, too, have found use for caves. For many years they were worked for the saltpetre with which our earth abounds. A great deal of the saltpetre used in making gunpowder for the war with Great Britain, in 1812–14, came from the Kentucky caves. Of late years other supplies have taken its place, and now the caverns

are only a little used for growing mushrooms, and storing various fruits and vegetables that keep better in a uniform, rather dry air. This underground world will remain of use to man, by giving him a place in which he can find an utter change from the life of the surface; a pure air, as well as a weird and wonderfully beautiful scenery.

European caves have also been of great use to the geologist, from the fact that in them are preserved the remains of many animals that would otherwise be unknown to us. Many of these caverns are very old. Some of them have been in existence for the inconceivable time of a million of years or more. They were open in a day when other animals lived than those now upon the earth. Some of these creatures used the caves for dwellings; others were swept into them by floods, or dragged in by beasts that preyed upon them. These remains have often become sealed up beneath the stalactites that form in the caves, and so have been well preserved from decay. By a careful system of excavations it is possible for the geologist to get access to these remains, and from them to infer the character of the land life in times that would otherwise be unknown to him.

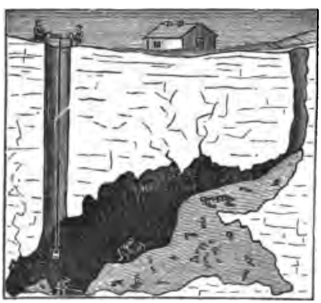


Fig. 39.
Bone Cave.

European caves contain more bones than American, because in the old days when they were formed hyenas and jackals abounded there. These creatures have the habit of dragging bones and dead bodies into caverns; and so they helped to stow away the remains of many animals which

have ceased to live, and which would be unknown to us but for the bones that are buried in the caverns.

Many of the most ancient remains of man, which go far back beyond the time of histories, have been found in the European caverns, mingled with the remains of animals that exist no longer.

There are some rarer sorts of caves that are not formed in the fashion of those in Kentucky. These are of three classes. The first very much resemble those of Kentucky in their general character and history; they are cut out of limestone by water, but the water is that of hot springs and not of the surface. This hot-spring water, ascending to the surface, may find limestone rocks in its path. In this case it generally dissolves out great chambers. Caves of this character are exceedingly irregular in their form. There are no domes, and, unlike surface caves, they may be formed below the level of the river into which their waters discharge. They are not very numerous, but exceedingly interesting on account of the valuable metallic deposits that they often contain. Some very important deposits of silver and gold ores occur in just such caves as these. The hot spring has first carved out the limestone, and then filled its space with ore.

The rarest, yet sometimes the most curious caves of all, are formed in lava streams. The flowing lava hardens on the top, because the air chills it, and makes an arch over the stream; then the supply of melted rock failing, the stream sinks down and leaves this arch, causing a cave that reaches from the base of the volcano to the top. Such a cave may be compared to the arches formed over temporary streams by the sharp cold of a frosty night that follows a winter thaw. The flood sinks away, and leaves the roof of ice hanging in the air above the course

that the waters have ceased to flow in. The next eruption of the volcano is apt to destroy this cave; but sometimes they endure for ages, being deeply buried beneath ashes and other lavas.

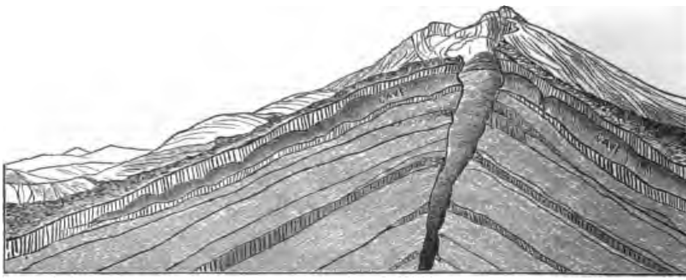


Fig. 40. Lava Caves on a Volcano.

We may complete our account of caves by a brief description of those made on the sea-shores by the beating of the waves.

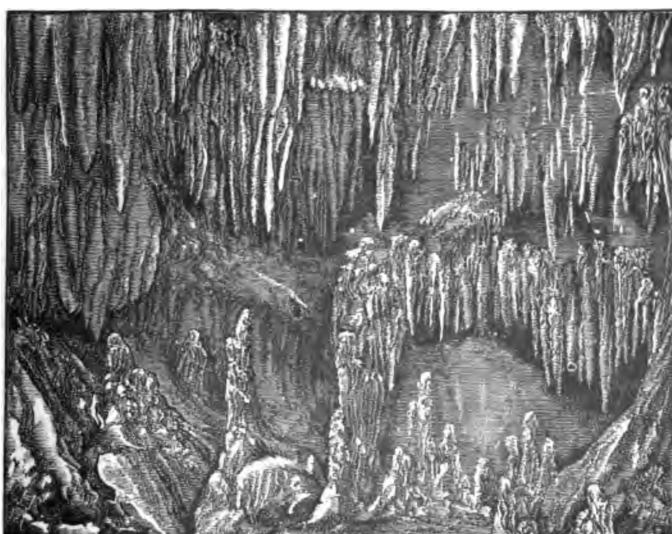
Wherever the coast is rocky and open to the wide water, the sea, in times of storm, hurls its waves with great power against the shore. If these waves held nothing but water, they, despite the fury of their blows, would not be able to wear the hard rocks to any great extent. But in most cases these waves have in their grip pebbles, or larger pieces of stone, which they hurl against the cliffs. Wherever there is a soft place in the rocks of the cliffs, the sea soon makes a wedge-shaped opening; into this opening the stones torn from the neighboring shore are collected, so that the waves have a constant supply of rocky fragments

Fig. 41. Sea Caves.

with which to batter the rocks. In this way they sometimes cut channels extending some hundreds of feet back from the sea front.

When the rocks of the shore have dykes or veins in them, these deposits are often softer than the rocks on which they lie, and so are excavated by the sea. All along the shores of New England we find many of these furrows, commonly called *chasms*. When the sea-waves rush freely into these furrows, their spray is sometimes during storms forced high into the air, when the crevice is commonly called a *spouting horn*.

These caves worn by the sea are never very large, and have none of the beauty or interest that belongs to those made in limestone rocks by the waters of the land.



View in Luray Cave.

CHAPTER IV.

THE DEPTHS OF THE EARTH.

LESSON I.

VOLCANOES.

WE should always bear in mind how small a part of the whole earth is really known, or we can know anything about. Our deepest mines have never gone more than one seven-thousandth part of the way from the surface to the centre. The upturned edges of stratified rocks make it possible for us to see somewhat further into

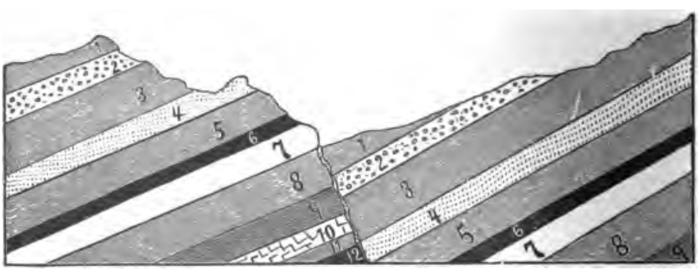


Fig. 42. Showing how Rocks are exposed by Tilting.

conditions of the interior, for they sometimes show us rocks that have been buried twenty thousand feet or more under the earth, and have since been exposed to the light of day by the squeezing and tearing that happens in mountain building; yet, with this help, we can never see in their natural state rocks that have been more than one five-

hundredth of the distance down to the earth's centre. In the diagram, such tilted rocks are shown.

The only way in which we can form any notion of what goes on at greater depths, is through volcanoes; they, therefore, deserve the careful study of every one who wishes to know the little that can be learned of the vast unknown region of the earth's interior.

Let us first see what volcanoes are, in order that we may learn what they can teach us of this inner mass of the earth.

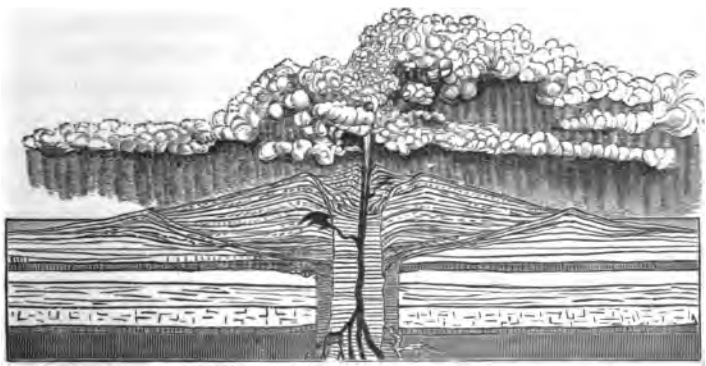


Fig. 43. Vesuvius in Eruption.

A volcano is an opening in the crust of the earth through which molten rock or lava and other stones, along with great quantities of steam, are thrown out with great violence into the air. This steam is heated far above the boiling point of water; up, indeed, to the melting point of rock, and escapes with such force that it drives the rocks before it, as by an explosion of gunpowder. Sometimes these pieces of rock are so pulverized that they are but dust, that floats away in the form of a cloud, and has been known to drift more than a thousand miles before it falls to earth; but the most of this rock falls near the mouth, and

makes a hill called the *volcanic cone.* It often but not always happens that the heat of these gases is so intense and long-continued, that the rocks through which the gas forces its way become melted, and flow out of the cone in the form of lava. But the amount of this lava is generally small compared with the cinders and ashes, and very small indeed compared with the escaping steam, which is the principal feature in all volcanic eruptions.

Volcanoes are never found in the middle of the continents, but only near the sea-shore, and over the bottom of the greater seas and oceans. Whenever we find old volcanoes in the middle of the lands, we find them no longer active, and we can prove that when they were active the sea lay near their bases.

This shows us that volcanoes are in some way connected with the processes that go on under the sea. There have been a great many theories to account for this relation between volcanoes and the sea; some have supposed that the sea-water found its way down through crevices to the central hot part of the earth, and was there changed into steam which poured out through the volcanoes; but we readily see it would be easier for the steam to come out of the passage through which the water went in to the heated region, than for it to force a new way to the surface, so we must give up this idea. The most reasonable view is, that the volcanoes are outbreaks of the steam that is confined in the rocks beneath the sea or near to it. A certain amount of water is fixed in the rocks when they are formed on the sea-floor. All our rocks made in water have from four to fifteen per cent of their mass made up of imprisoned water. This water becomes heated because the beds laid down on top of it are very thick, and act like a blanket to keep the earth's heat in. In the

course of ages this water may come to have a heat as great as that of melted iron. Now, if any crack is found in the overlying beds that will let these gases escape, we shall have a volcano. This will account for the fact that volcanoes are jets of very hot steam, and that they always lie near the sea-shore or on its bottom.

The reason why volcanoes do not occur far away from sea-floors is probably because it is only on these parts of the surface that the great blankets of rock are laid down on the earth.

We can help ourselves to figure this effect of beds of rock in raising the heat of rocks below them, if we remember that over all the earth's surface a constant flow of heat is streaming out through the earth and going away among the stars. Enough of this heat escapes each year, from every square mile of the earth's surface, to boil a great many barrels of water. If the reader could heap any kind of rocks on the ground where he stands, so that the surface would be covered to the depth of two miles, the water in the soil would, on account of this *blanket* of rock, rise slowly to a greater heat than that of boiling water.

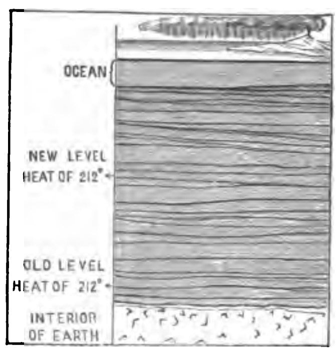


Fig. 44. Rise of Heat in Rocks.

Most volcanoes are found in places where civilized men have not had a chance to watch them for a very long while. The history of only three is known for as many as one thousand years. These are Vesuvius and Ætna in Italy, and Skaptar Jokul in Iceland. Of Vesuvius and Ætna, we have some account for more than two thousand

years. These histories show us that volcanoes are not commonly in a state of activity. More than half their life is spent in a state of repose, their powers slumbering below the earth. Sometimes these still times continue for several hundred years. Vesuvius was not even known to be a volcano until the year 79, though the region about it had been dwelt in by the Greeks and Romans for at least four hundred years before that time. It was covered with forests and tilled fields. At that day men had not studied the forms of its surface, else they would have known that its cup-like shape, and the nature of the ashes that made up the mountain, marked it as a volcano. Seventy-nine years after Christ's birth, the silent mountain stood amid one of the most fertile and thickly peopled parts of the earth. It was the richest part of the Roman Empire in its most prosperous days. Early in that year there began to be earthquakes in the region about it. Still, though there were volcanoes on the island of Ischia, which lies within sight of Vesuvius, that had proved very destructive to life and property, no one thought of the danger of an explosion from the long silent Vesuvius. Finally, a most frightful explosion took place. The upper part of the mountain was blown to pieces, and the country for many miles about was rained on for days by stones and ashes, falling so thickly that a perfect darkness was made. Men and beasts were killed, even a dozen miles away, by the shower of hot stones, and all this beautiful country was reduced to ruin. The famous Roman naturalist, Pliny the elder, who was admiral of a fleet stationed at Misenum in that district, a town about twenty miles from the mountain, lost his life at a point over a dozen miles away from the volcano, having been suffocated by the vapors of the eruption in his effort to save

the inhabitants of the shore. So severe was the shower of ashes, that his attendants could not bear his body away from the place where he had met his death.

At least two large and wealthy cities, Herculaneum and Pompeii, were buried beneath the prodigious masses of ashes or small stones that were thrown out from the volcano, or overwhelmed in the mud made by the heavy rains, which always come with a great eruption. There were doubtless many small villages overwhelmed at the same time, the names of which are unknown to us, for it is only by chance that we learned of the destruction that came upon Herculaneum and Pompeii. The accounts written at the time simply say that many places were destroyed.

After this eruption, others came at long intervals, sometimes over a hundred years going by without the least sign of activity in the mountain, so that a good part became covered with vineyards and gardens. Then, with a period of earthquakes that set all the mountain to trembling, the volcano would again burst forth. It was not until after it had been active for about a thousand years that it began to throw out lava. Lava eruptions have been growing steadily more common than of old, and the eruptions have been growing more frequent and less violent. For, as a general rule with volcanoes, where their eruptions come only at long intervals, they are much more violent than they are when they quickly follow each other. A little volcano, called Stromboli, which lies between Vesuvius and Ætna, has been in constant eruption for centuries, scarcely a day passing when it does not throw out some fiery gas and melted stones; but its eruptions are never very violent. It is to be noticed that the larger the volcano, the more likely it is

to throw out lava. Ætna has had many worse lava flows than Vesuvius, and is one of the best places to study such streams.

When lava escapes from a volcano, it is generally very fluid. Sometimes it appears almost as liquid as water, though it really is more like melted lead or quicksilver, which are less fluid than water, though they flow with ease. The lava generally flows very quickly when it escapes from the crater; but it soon begins to cool, and forms a solid crust upon its surface that makes it hard for it to creep along. Finally, it crawls so slowly, pushing along a mass of broken solid lava in front of it, that it looks like a large heap of rolling stones; yet the lava within the stream stays fluid, and for months it may crawl along in this fashion, making only a few hundred feet of advance in a day. Still it is strong enough to overwhelm towns and destroy fields in its course. Sometimes the hard coating of frozen lava will break open and let the fluid interior out in a fresh stream, which in time becomes clogged in the same way. It often happens that these lava streams fall into the valleys of rivers. It then drives the water into steam, and effaces the course of the river. After the lava has cooled, the river commonly cuts itself a new bed alongside of the lava; often there is a stream on either side of the lava, and in time these wear down so deep that the lava is left on a hill-top. This has often occurred in California, where volcanoes, now extinct, once filled to the very brim with lava the valleys that lead from the Sierra Nevada. We know much of these old Californian streams, for their beds contain gold among the gravel, and a good deal of mining is carried on in their ancient beds. In the figure No. 45, the dotted line shows the position of the old valley which has been filled with

lava, while below we see the present valleys. The old river bed, containing gold, lies under the lava stream, which now caps a hill.

Although volcanoes rarely give out large amounts of lava, there are some places in the world where there are very large regions that have been covered with these floods of molten rock. One of these in California, Oregon, and Washington Territory, is nearly as large as France.

Although volcanoes are among the most violent and seemingly disordered of the earth's works, they play a definite and bountiful part in its machinery. If the world

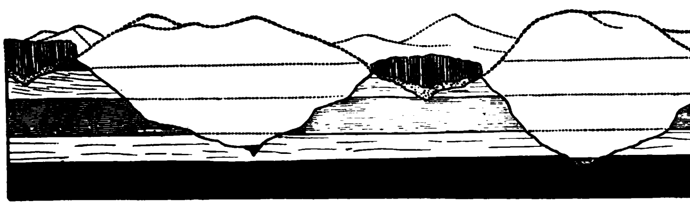
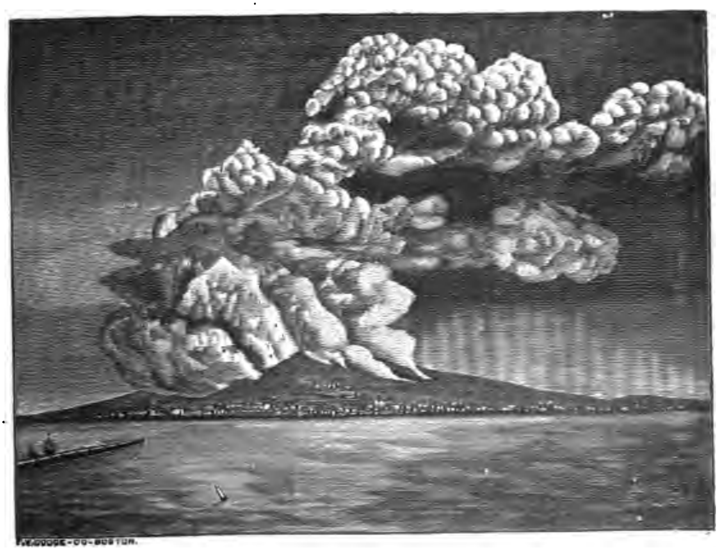


Fig. 45.
Old River Beds filled with Lava.

were without them, it is hard to see how life could long exist. This seems a paradox, but its truth is easily made plain. We have seen that the plants of the earth live by taking the carbonic dioxide from the air. In an atmosphere without this gaseous carbon plants could not grow; and, as animals depend on plants for their food, they, too, have the liveliest interest in this element in the air. The amount of this carbon is never large, not exceeding one three-hundredth of its bulk. If there were not means whereby this carbon could come back to the air, it would require only a few centuries to make the supply so small that plants could not grow. A great deal of the

carbonic dioxide, perhaps nine-tenths, that goes into the plant, comes back to the air in their decay; but every bit of coal that is formed, every grain of limestone that is deposited on the sea-floor, takes so much carbon from the air and lays it away in the rocks; so that it is certain that the vegetable world could not long endure without some renewal of the carbon supply in the air. The principal way in which this buried carbon can get back to the air is through the gases that volcanoes throw out in their times of eruption. Although the most of this gas they pour forth is water in the state of steam, there is a considerable amount of carbonic acid gas thrown out in every eruption. Sometimes so great is the quantity that it suffocates the animals for some miles distant about the crater. We do not notice it much in an ordinary eruption, for the reason that the gas is taken into the water and steam, and so locked up there that it does not affect life; but in an eruption of Vesuvius or Ætna there is as much of this gas of carbon given forth to the air as would be taken from it by the burial of a large amount of coal or limestone. As volcanoes are continually in eruption in one part of the earth or another, it follows that they play a most necessary part in keeping the world fit for life; and the destruction they do is of trifling importance compared with the benefits they confer. This adds another to the many proofs that this earth is wonderfully arranged for the uses of living beings. We have seen that the orderly work of the air and the waters, in all their manifold actions, seem to foster this life; but even the most violent and seemingly destructive actions of volcanoes also aid in making the conditions that life requires. When we look at the buried cities of Pompeii and Herculaneum, or behold the ravaged vineyards and olive orchards about

Vesuvius, we may set against this account of ill the fact that in every eruption of Vesuvius there comes forth the carbon that is to find its place in the life of the whole world; so that the damage it brings about is trifling compared with the benefits it confers.



Last Stages of a great Eruption of Vesuvius, from a photograph.

LESSON II.

ON THE CURRENTS OF AIR AND SEA.

WE have already spoken of the atmosphere in a preceding chapter. We will now look more closely into the work that comes from the action of its currents, the winds.

The life of our earth is of two kinds: the life of animated nature, and the life of the inanimate world, shown in the movements of the air and water, and the other motions, such as those of volcanoes. Except the disturbances that come from beneath the earth, all its motions are derived from the sun's heat; all the life of animals and plants, all the currents of the air, the rivers, and the oceans, every stir of its surface, is due to the force that comes from the sun and stars. The motions of our own limbs, even the beating of our hearts, are only forms of force that comes to the earth from the great sources of power, the sun and the fixed stars. The sun's heat causes the plants to grow; and it is this solar force that comes to us in our food, and is the support of all animal bodies. Every wind that blows, every stream that runs, on land or in the sea, moves because impelled by this power from beyond the earth. If our earth could be cut off from these sources of power, all its life would soon become stilled. One night, of a few months' duration, would bring its whole surface to a cold of more than one hundred degrees below zero of Fahrenheit, and all the animate and inanimate life would be stilled; the seas and rivers would change to motionless ice, and, until the day came again, no motions, save those of the earthquake and the volcano, would occur upon the earth.

Since this world is moved by the force that comes from the sun, we should get some idea of the way in which this heat comes to us, and the mode in which it works after it has arrived on the earth.

This solar force comes to the earth in the form of heat and light. Both the heat and light are necessary for the machinery of animal and vegetable bodies, but the movements of the winds, the waves, and the currents of the sea require only the heat for their action. The supply of light and heat comes to the earth from two different sources. Somewhere near one-half the heat comes from the fixed stars. This heat from the far-away stars descends equally on all parts of the earth's surface; but, if it alone came to the earth, there would still be no movement for it; the oceans would be frozen to their bottoms, and life of all kinds would be impossible. All that this star heat does is to lift the general temperature of the earth's surface from a far greater cold to an average temperature of about one hundred degrees below zero of Fahrenheit. Although this seems but a poor gift, it is still of priceless value, as it makes it possible for the sun to do its good work of quickening life on the earth; but for this help from the stars, the sun could not accomplish this task; it alone would have too much work to do.

The sun gives us both light and heat; but, in place of giving it as the stars give their heat, equally over all the surface, it pours a great amount of this light and heat upon the regions between the tropics, and gives much less to the regions about the poles. If this heat stayed where it fell, or if, like the light, it were a momentary thing, disappearing as soon as the earth turned its face away from the sun in the night time, then the world would fare badly; for, during the mid-day at the tropics, the heat

would be too great for life to endure, and in the night everything would perish in a frost of more than a hundred degrees below zero.

Fortunately heat can be stored up, as light cannot be. The rocks and the air can take in some of it, and the water can take in a very large quantity. This heat is given out again, after having been stored away for a time. Thus, when the night comes, in place of the thermometer falling to one hundred degrees below zero at dawn on a summer's night in the tropics, it rarely goes below sixty above zero; because these things which have been taking up heat all day proceed to give it out in steady streams. So, too, in the winter, the earth and seas slowly yield up the heat the summer gave them to moderate the rigors of the cold seasons. Thus it happens, that islands, even in seas near the poles, have often a somewhat uniform climate in winter and summer. The average difference of temperature of the months in Cornwall in southern England not being more than thirty degrees in any one year. But the most important effect of this great heat-storing ability of water is found in the power it has of carrying heat from the equatorial regions to the poles. This it does in the way we shall soon consider. If we watch a heated stove in the middle of a large room, the walls of which are cooled by the outside winter air, we easily see, by the aid of a little smoke in the room, that the air rises over the stove to the ceiling, floats off to the sides of the room, falls down there to the floor, and then runs along it to the stove, making a continuous round. This is because heated air is much expanded, and, therefore, greatly lighter than the cold. We may illustrate this by means of a paper balloon, with an open mouth below, underneath which a small piece of sponge dipped

in turpentine or alcohol is hung. This sponge being fired, the heated air will swell the balloon, and lift it far above the earth. The first balloons ever used to lift men into the air were of this nature.

The circulation of the air about the stove is exactly parallelled by the circulation of the air on the earth. The region between the tropics is so hot that the air is impelled to rise; to fill the vacant space, the air rushes in from the regions to the north and south in the strong gale we call the trade winds. The upper air streams off towards the poles in a mighty flood as wide as the seas;

Fig. 46. Diagram of Air Currents.

on the high mountains near the tropics we may feel it always blowing a steady gale, never ceasing by day or night for ages.

If the earth stood still on its axis, these winds would come straight down the surface of the earth towards the equator following the meridians; but, because the earth spins around on the polar axis from west to east, they come slantingly down upon the equator from the north-east and the south-east. It is a little difficult to give a simple and clear explanation of this slanting course of the winds that blow towards the equator. It may best be understood by spinning a round, flat piece of cardboard on a central

point, and trying to roll a marble from the centre to the outer edge. It will be found that the marble will not roll along the short, straight line from the centre to the circumference, but will follow a curved line, coming to the edge as shown in the figure. This is because the marble has in its course always a less rate of spinning than the card over which it is travelling. The friction on the card makes it spin around with it; but it comes to each part on its course at the rate of the part which it has just left. A particle of air, when it starts in the trade winds on its journey to the equator, is spinning round with the world on which it lies at the rate of about five hundred miles an hour; when it gets to the equator, it must travel a thousand miles an hour. The result is that it lags behind at every stage of the journey, just as the marble does, and so comes obliquely from the north-east and south-east, and not squarely down upon the equator. All this has a great importance, as we shall now see.

Fig. 47. Deflection of Air Currents.

These trade winds blow strongly, so that they send a ship at great speed, and, as may be imagined, they sweep the surface water of the sea along with them at the rate of two or three miles an hour. This water flows in the same direction as the wind; and so, as there are two streams of water, one from the south-east and one from the north-east, each as wide as the ocean in which they lie, the two pressing against each other at the equator make a current two or three hundred miles wide, flowing towards the west at the rate of several miles an hour, or about as swift

as a large river. This water is very warm, from the heat given it by a tropical, overhead sun; so it is a vast hot stream carrying perhaps more water than all the rivers of the world.

If there were no lands in the tropics, this river of the sea would flow around the earth as a great girdle of running water; but when it strikes against the shores, it is split in two, and runs as two streams towards either pole. There are two of these streams in the Atlantic and two in the Pacific Ocean; in the Indian Ocean, because there is so much land near by in the northward, the trade winds are not steady enough to make any very distinct current. We know only one of these streams at all well. This is that known as the Gulf Stream, because a part of its water comes out of the Gulf of Mexico, into which it flows from the Caribbean Sea. This stream flows into the north Atlantic. When it starts from the West Indian Islands, it is a stream about one hundred miles wide and several hundred feet deep, flowing at the rate of four miles an hour. As it gets northward it widens and becomes more shallow, and steadily sinks in temperature. As far north as England it has a very gentle current, but is still much warmer than the air usually is.

As it goes northward, this stream leaves the American shore which turned it northwards, and moves to the eastward, crossing the Atlantic. If the reader has seen why the air currents turned to the west in going southward, in the trade winds, it will now be easy to understand why the current of the sea strikes off to the east in going northward. Each particle of water, when it leaves Florida, is moving to the east, in the spinning of the earth on its axis at the rate of several hundred miles an hour. As it goes towards the pole it is constantly coming

into regions which have a less movement to the east, so its momentum causes it to outrun the easterly motion of the earth at these points, and to swing off to the east or the direction in which the earth is turning.

These waters that seek the pole return southwards in the depths of the sea in southward-setting currents that move slowly along the bottom, or creep along the western shores of the oceans. So the waters of the seas are constantly sent towards the poles in warm currents, and returned in cold streams to the tropics, to be again charged with the life-giving heat and sent again to high latitudes.

If the heat of the water stayed where it fell, then the tropics would be too hot for life; while, all about the poles, even as far south as New England, the ocean would be frozen so there would be only a little strip of the earth in either hemisphere fit for life. But, by this machinery of the moving waters, the temperature of the earth is so balanced that but little of it is not suited to some forms of animals and plants. We get an idea of the power of these ocean currents when we know that the Gulf Stream sends as much heat to the region within the Arctic circle as comes upon that part of the earth from the sun.

Now, heat not only affords the possibility of life, but it is the power that sets all of its machinery in motion; so it happens that this machinery of the winds serves to distribute the source of life over the earth, equalizing it so that the whole of the earth's seas and lands give some chance to living beings.

The winds alone cannot do this work of distributing the earth's heat, for the air cannot hold much heat stored in its particles. If it were not for the currents of the sea, there would be no chance of having enough heat carried to the regions about the poles to keep them from perpet-

ual frost, or enough taken away from the tropics to keep their lands and seas from becoming so hot that few living things could endure the climate. But, in a smaller and local way, the winds do a great deal of work. They carry the warmth and moisture from the seas into the lands, giving them their needed quantities of these all-important things.

It is easy to see that the shape of the lands fixes the course of these ocean streams. The great Gulf Stream, that flows into the north Atlantic, finds an open passage-way far to the north; on the other hand, the great stream of the Pacific, the Japan Current, is shut out from the Arctic Sea by the peninsulas of Alaska and eastern Asia, so that it cannot pour in its warm waters to relieve the cold about the poles. If these lands should sink down beneath the sea, as the lands often do, letting the Pacific stream into the Arctic Ocean, the result would be that the tropics would become cooler, and the northern regions a good deal warmer than they are at present. Many of the wonderful changes of climate that we know to have occurred in the past are probably to be explained by such change in the direction in which the ocean currents flow. When they can reach the poles in strong streams, the tropics become cooled by the heat that the waters bear away from them, and the regions around the poles warmed by their waters. When the lands force the ocean currents from the poles, the tropics become hotter, and the lands and seas of high latitudes are given over to intense, life-destroying cold.

There are probably many other causes of climatic changes in the earth's surface. The sun's heat may vary, or the changes in the earth's path about it may alter so that the winter and summer seasons in any country are

sometimes of nearly the same temperature, and again, more different than they now are. But this change in the course of the ocean streams, depending on alterations in the position of the ocean currents, is probably the principal cause of the great climatic changes in the past history of the earth. We know that the course of these streams depends on the shape of the lands; we know, also, that the lands are constantly changing their shapes; so it follows that, as the distribution of the heat on the earth's surface depends mainly on those streams, the temperature of any place must be made greatly to vary, in different ages of the earth's history.

Diagram showing the change of Behring's Strait necessary to warm Northern Regions.

CHAPTER V.

IRREGULARITIES OF THE EARTH.

LESSON I.

HILLS, MOUNTAINS, VALLEYS, AND CONTINENTS

THE surface of the earth abounds in irregular elevations, which have been formed in various ways. When the running water has cut away about a mass of earth or rock, we term it a hill. The figure shows the form of a hill, the dotted lines showing the rock that has been cut away in its formation. As nearly every region has had running water upon it, hills are found everywhere. Mountains, at first sight, look like greater hills, but we find that they are built in a different manner. They are made by a folding of the rocks of which they are composed, as shown in the figure. These rocks were originally flat, lying like those in the hill, but, by a way

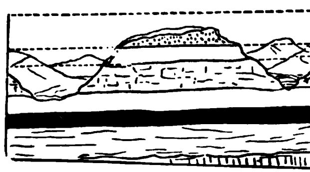


Fig. 48.
Section of Hill.

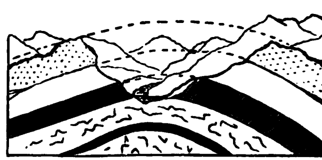


Fig. 49.
Section of Mountain.

which we will now consider, they have been crumpled up so that they lie like a mass of wrinkled paper. If we look closely at any mountain, we see that a great part of it has been cut away by rivers, so that the hill-making forces are as evident there as elsewhere. We may properly say that every mountain is in a certain sense a *hill*, while hills proper are not mountains.

The cause of this crumpling of the rocks in a mountain is a pressure coming horizontally through the earth. We may represent it by taking a number of sheets of paper, each of which may stand for a layer of rock, and pressing them from the sides, so that they may be forced to wrinkle, as shown in the figure. This is the way in which this wrinkling is brought about:

The earth is very hot in the inside, as we know from the fact that volcanoes throw out masses of rock melted by heat, and that all our mines grow hotter as they descend. Now, the space outside of the earth is extremely cold, as is shown by the fact that all very high mountains, even under the tropics, have snow that does not melt in midsummer. If, in the hottest summer day, we should ascend to the height of five miles above the earth, we should find the air at about zero. This heat of the earth's depths is constantly leaking out into the spaces of the sky; enough passes off each day to melt somewhere about one hundred cubic miles of ice. Now, as the earth loses heat, it shrinks. All substances, except water, shrink in cooling. A familiar example of this is seen in the rails of a railway. In the heat of summer, they swell until their ends come close together; in the winter, they shrink until they are some distance apart. A mass of melted stuff, such as glass, will generally become one-tenth smaller when it loses enough heat to freeze or become solid.

From this loss of heat, the earth constantly becomes smaller. Take any point in our solid rocks: it is certain that one thousand years ago this point was a little further from the earth's centre than at present, because the shrinking of the earth in one thousand years amounts to a foot or more of its diameter. In this shrinking, it is the deeper part of the earth that grows smaller. The outer part, that is folded into our mountains, has long been so cooled that it had no great amount of heat to lose, and so of late it has not shrunk. All the inner region has been steadily shrinking since the world began. It is easy to see that this outer part must wrinkle on the outside. To compare small things to great, we may consider an apple as representing the earth, and its skin as answering to the cold outer shell. When the apple dries up, the outer skin wrinkles, because it loses a little of the water that escapes. Conceive a loss of heat to bring about the shrinkage in the apple, and we have a close likeness between the little sphere of the fruit and the world that gave it life.

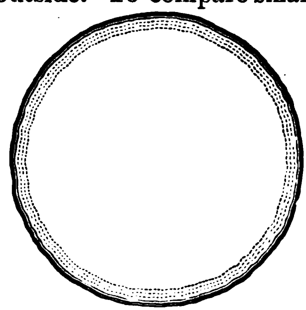


Fig. 50. Wrinkling of Earth or Apple.

If our mountains had not been worn down by the action of water, they would appear vastly higher than they are. The very highest has its top less than six miles above the sea; but, if we could put on it all that the water has worn away, it would probably be twice as high.

Yet it must not be supposed that these mountains were ever much higher than at present; for, in fact, the mountains grow slowly upward, while the streams of running water, or the ice streams that often form in their high-up

valleys, cut them down. So slowly do our mountains generally lift themselves, that a stream flowing across them is sometimes able to keep its bed cut open as the mountain rises, the ridge never moving upwards so suddenly that the river found an impassable dam in its way.

The simplest mountains are like the Alleghenies, where a number of long, low ridges, looking something like boats turned upside down, lie side by side, closely crowded together. In more complicated mountains, the smaller folds rest upon larger folds, as shown in the figure below, the whole worn down in a curious way by the streams. It is in such mountains as the Alps, where we have this very

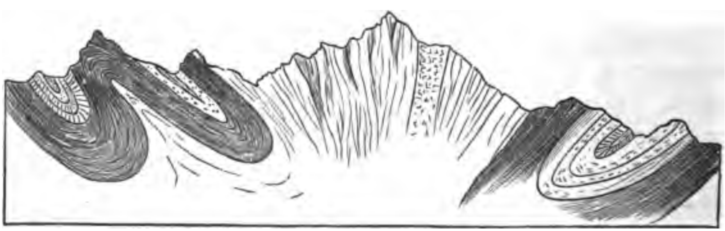


Fig. 51. Section through Mt. Blanc.

complicated structure, that we find the finest mountain scenery.

If mountains cease to grow, the streams gradually plane them down until the surface becomes nearly level again, and only a geologist can see that the country has its rocks arranged in a mountainous way. There are many countries where such worn-down mountains occur, and they are not infrequent in America, — the eastern part of New England, including all of Rhode Island and the most part of Massachusetts and Maine, is upon such worn-down mountains.

One of the advantages of this peculiar structure is, that it enables us to get at many stores of mineral wealth from which we would otherwise have been debarred by their deep burial. We see by the diagram how a seam of coal or a bed of iron ore may be brought to the light, which otherwise would have been deeply buried in the earth, beyond the reach of man.

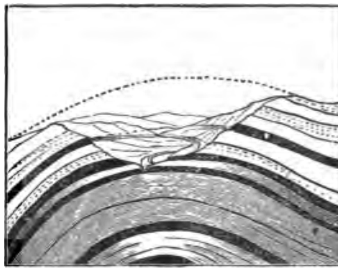


Fig. 52. Coal Beds opened by Fold.

Mountain ridges are rarely found alone. When they occur at all, they are generally in long sets of ridges, which have each the same general direction as the main chain. A familiar instance of this is seen in the ridges of the Allegheny mountains or of the larger Appalachian series of mountains, of which the Alleghenies form but a part. Rather more than one-half of the earth's surface has been pushed into the crumpled form of mountain folds. In fact, nearly every part of our rocks that has been made for a long while shows some marks of crumpling under this pressure that builds mountains, and in time even the most level rocks will probably be twisted by this force pressing against their sides.

These foldings of the rocks may be of any size, from those that form the greater mountains down through those of less and less dimensions, until the fold is only an inch or so in width. In the larger folds, the thickness of the folded rocks is great; while, in the smaller folds, the beds may not be thicker than this paper.

Besides the steep, sharp foldings in the mountains, the earth's crust has folded in broader curves to form the

continents and great basins. These folds are immensely broad and of very gentle curves. Thus, while a mountain may be nearly as high as it is broad, the continental

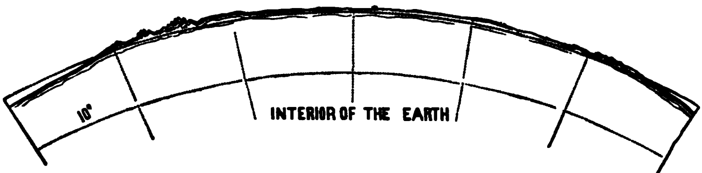


Fig. 53. **Section across North America.**

fold is from one hundred to one thousand times as wide as it is high. It is not certain just how these continents are formed, but they probably arise from the folding of thicker parts of the earth's crust than are crumpled together in the formation of mountains, — a folding that is also due to the gradual escape of heat from the earth's interior.

It is worth our while to notice that, although the heat that comes to the earth from the sun and stars serves, by setting in motion the machinery of the rains and waves, to wear down the mountains and the continents, the heat that goes from the interior to the stellar spaces causes the mountains and continents continually to rise and replace the wear effected by the ever-falling heat. The heat, falling on to the earth, tends to reduce all its irregularities to a plane; the heat that flies upward from its depths serves to make it irregular, — to build mountain and continent as fast as rain and wave wear them down.

CHAPTER VI.

ORIGIN OF VALLEYS AND LAKES.

LESSON I.

RIVER VALLEYS.

ALTHOUGH the continents and mountains form the greatest irregularities of the earth's surface, there are other and commoner features in the land that we cannot pass by. Nearly every part of the earth's surface, above the line of the sea, is formed into valleys, and in many of these valleys there are deposits of fresh or salt water, termed *lakes.*

These valleys are of all scales of magnitude, from those that may be bridged with the foot, to those that include half a continent within their bounds.

To understand how valleys are formed, we should observe the action of rain-water on some area of smoothed land, such as a newly-ploughed field over which a roller has been drawn, bringing its surface to an even slope. We see that the water at once carves out for itself a system of channels which connect with each other, so that a picture of these streamlets will look something like a map of any large river system.

Whenever the seas give up the lands to the air, they are at once seized upon by the rain-water, and their surface brought into such a system of valleys; the only exceptions being when, as is the case on only a few spots

upon the earth's surface, there is too little rain to make any rivers at all.

Each of these river valleys has certain features which are common to all others, though no two are just alike. Every river valley has three principal parts: the place where the river is actually cutting its way, which is termed the channel; the alluvial plain on either side; and the far wider section on either side, which is termed the *water-shed* of the river.

The relative proportion and relations of these two elements of the valley vary very much, which gives the most of the variety to our river basins.

Fig. 54.
Section across River Valley.

The channel of the river is principally due to its mechanical cutting power on the rocks through which it goes. On either side, the alluvial plain marks the place where the stream has recently been at work, but from which it has swung away. On either side, but further away from the channel, is a broad slope towards the stream, which may be miles in width, and is nearly always cut up by tributary streams, each essentially like the main river, only smaller.

To get a good idea of a river's history, we should go to some of its mountain tributaries, — for all very large

rivers head in mountains,—see there the first steps of the water; then trace this stream to the sea. In this mountain stream we shall find the water rushing rapidly down a steep slope cut in the solid rocks. These rocks themselves are the waste of old rivers, which was long ago carried to the sea from old lands, built on the sea-floor, and uplifted into the land again, where we find the river now carving them. They may be in the shape of sandstones, shales, and limestones, or they may have been altered by heat into the shape of granites or other crystallized rocks. We shall find the mountain-stream bed full of great rounded or angular stones, which have been riven from the banks by the roots of trees or the frost, or released by the process of decay, which works into every fissure of the rocks, and leaves them free to fall. In the dry season, the clear water of the stream tumbles about among the stones, making a great deal of noise, but doing little work of wearing; but in the times of flood we shall find it full of muddy water, and we may see the large stones pounding along, bruising their neighbors, and wearing the bed over which they are forced to move. Now and then, landslides bring a great amount of rubbish into the bed, so that the stream is dammed for a time; but its waters soon overcome the barrier, and bear its earth and stones on in the flood. These times of flood are the only occasions when the stream becomes a rock-grinding mill; and its power is due to the swiftness of the waters, and the ease with which they urge the stones down the steep slope of the bed. In this, the torrent part of a river, the stream generally falls fifty feet, or more, to the mile. If its slope is steeper, it often clears away the greater part of the stones, and flows over the lower rock-bed.

Soon the brook, swollen by tributaries from either side,

finds its way out of the gorge in which it was born, and enters a wider valley, where it falls less rapidly, and takes on the character of a little river. The first change we notice is that the river no longer flows in a narrow, V-shaped gorge, with no flat land along it, but it now has a little edge of stones, sand, and earth on either side of its waters. Here lie the bits of stone which its diminished current no longer permits it to carry; for the swift streams above send down larger pebbles than the river can now carry away. They have to remain until they are decayed into pieces small enough for the stream to bear onward. As we descend further towards the mouth, we find that the current, except for occasional falls or rapids, becomes constantly slower, so that these stones lodge on the sides of the stream, making wider and wider terraces on either side of its path. This accumulation of rubbish causes the stream frequently to change its bed. In these ways it cuts away on one side of the alluvial deposit, and fills in on the other. Each time it travels over the deposits of pebbles, it takes out the part that is decayed to sufficient fineness to be borne along; the larger pieces soon lodge again in the terrace-beds.

When the stream is at its flood height, it commonly overflows much of this alluvial plain, and leaves on it a coating of fine mud, which is generally built into a very fertile soil. This soil is often very deep, but below it we find the layer of stones which the stream had not force enough to carry with it.

Near the mouth of a great river, these alluvial lands rapidly widen, and form the delta, which is, in reality, not a thing by itself, but is the broadened ends of the alluvial plains that border the stream, from the time it became a river; that is, when, in its head-waters, the fall

of its bed became too slight to carry all the rubbish the mountain torrents sent into it.

The only striking variety given to a river is where some harder rocks cross its bed, making a fall. Falls are formed in several ways. One way is when a trap dyke crosses a stream, forming a dam of rock so hard that the stream has difficulty in cutting through it. Such falls are rare; they hardly occur in any great streams. Another and commoner way is when the bedded rocks that cross the stream slope down towards its head, as shown in the diagram, Fig. 55. In this case, if there be a hard bed also with soft rocks below it, a fall will be formed. The water plunges over the hard bed, and, by dashing the stones about, wears away the soft bed, making a steep and often an over-hanging cliff.

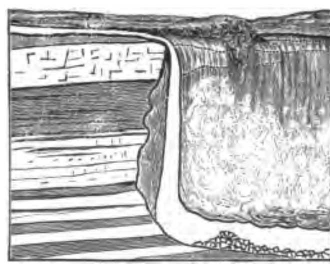


Fig. 55. Section of Niagara Falls.

The falls of Niagara, as represented in the diagram, are formed in this way. On top is a hard limestone, known to geologists as the Niagara limestone, which happens to cross the river at this point; below is a soft slate, which the whirling waters at the foot of the fall easily cut away. From time to time, this undercutting causes the overhanging hard layer to fall to the base, where the surging waters use the fragments as tools to cut away still more of the soft layer. In this work, the beating spray, which lashes against the rock, gives much help. So the fall is slowly working up stream, at the rate of a few feet in a hundred years. All falls of this nature work up stream in the same fashion, becoming lower as the hard layer sinks downwards towards

the stream-bed; as will be easily seen by inspecting the diagram of Niagara Falls.

The falls of the Ohio, at Louisville, afford yet another and the rarest sort of fall. There the river flows over an old coral reef, which was built into rocks formed long before the coal measures. This coral reef is much harder than the other rock of the country, so that the river is thrown into cascades where it crosses its surface.

This is a brief account of the course of the water in the stream itself, and of the causes that give its course and shape its bed. The causes of river-courses, and the many details of its shape, are not easily understood, and

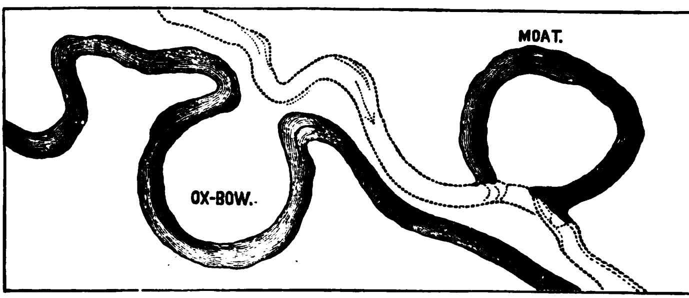


Fig. 56. Change of River Channels.

depend on a thousand local conditions. The constant swings of a river are made to get away from the waste which its current is continually trying to bear along; a work which, from the quantity of this waste, it cannot well do. All our rivers are overburdened by their sediments. In their struggle with the waste, they are thrown into strange turns and windings, called ox-bows, which are found only in sluggish parts of streams. These ox-bows are often cut across by the current, leaving what are sometimes called moats, from their likeness to the ditches dug about old castles, and other tower strongholds.

The bed of a river, though it seems to move mainly to and fro through its alluvial plain, is generally cutting downward into the rock that underlies it; the result is, that it leaves more or less of these alluvial fields high upon the banks on either side of the stream. These shreds of the old alluvial plains show the successive levels of the stream, as it has cut downward in its endless wearing of the rocks over which it flows. Sometimes there are as many as half a dozen of these old levels marked in the terraces of the stream. Very good examples of these occur along the Connecticut River, and most of the other New England streams. They have been considered as proofs that

Fig. 57. Terraces of River Gravel.

the river was once much larger than it now is, but this is not the case; for, if the river had ever been able to fill its valley to the level of these high terraces, it would have swept them away altogether on account of the swiftness of its stream. The diagram shows the general position of terraces in a river valley, and the old levels of the river when they were formed. We must imagine that, at each level, the river swung to and fro a great deal, always cutting slowly downwards.

On each side of the river, as before remarked, there is a gentle slope upward to the "divide," or separation

line between any river valley and the next adjacent stream. This slope is caused in part by the cutting of the small tributary streams, and in part by the dissolving of the rock by the water percolating through the soil.

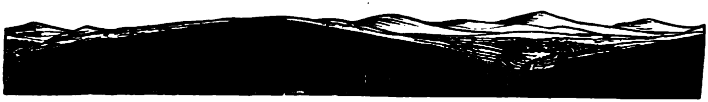


Fig. 58.
Divide between two Streams.

In some few cases where a stream has its head-waters in a country where the rainfall is large, and then flows through a region where there is scarcely any rainfall, the sides of the stream in the desert region have no chance

Fig. 59.
Colorado Cañon.

to be cut down, so the river carves out a very deep track, through which it flows. The best example of this in the world is the great Colorado Cañon, where the river, plentifully fed at its head-waters in the Rocky Mountains, pours for a long distance through a nearly rainless coun-

try, where it has carved out a very deep bed with walls thousands of feet high on either side.

In a few cases we have valleys, such as the famous Yosemite, where the trough through which the river flows was probably made by the fracture of the rocks by faults with the down-sinking of the region in which the valley lies.

Sometimes, as in the case of the Connecticut, the Merrimac, and other rivers of New England, the river valley is first carved out by a river, and then, becoming the pathway of a glacier, is widened by the ice stream. In this way, many small mountain valleys which are cut into V-shaped trenches by rivers, have been changed into U-shaped valleys by the wider streams of ice that filled them in glacial times. This is because the swift-running brook cuts, at any one time, only the narrow space, perhaps ten feet wide, of its bed. The slow glacier moves, say, three feet a day, while the living water flows, say, sixty miles a day; so the glacial stream is necessarily a very wide and deep one, and grinds a broad channel.

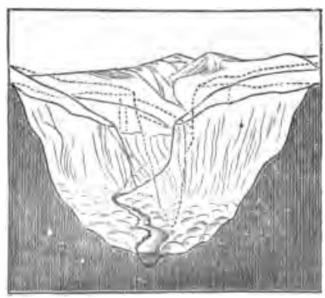


Fig. 60. River gorge widened by ice.

We may close our glance at river valleys by stating that they represent the great erosion work of the world. They are the result of a force that comes to the earth through sunshine, and acts through running water, working to bear away the sediment from the land into the sea, where it may be made to nourish life, and to form new strata in the sea-floor, — strata which are, it may be, destined to rise again into lands, to be again subject to the wear of the streams in ages to come.

Besides the valleys carved out by rivers, and the forces that produce lakes, there are some great valleys that have been shaped by the action of the ocean tides, while the lands were under water. Although these sea-carved valleys are rare, it is worth our while to study them, as they give us an idea of the way in which wearing goes on upon the ocean shore and on the bottom of the sea near the land.

The winds and waves which the sea sends against the shore have no power of cutting valleys. They batter the shore most effectively on the headlands. Their waves weaken as they enter a bay. Thus, in time, they tend to bring the coast to a straight line, by wearing off the headlands, and filling the waste into the inlets between the promontories. The tides, however, work in the reverse way. On the shores of the ocean, twice each day, there is from the deep a rush of water that passes up every indentation, stirring up the mud, and mixing it with the water. As these tides go out, they drag back this dissolved sediment, and draw pebbles along the bottom out into the open sea. Now, these tide-waves, unlike the wind waves, rise much higher in the heads of bays and gulfs than they do on the shore; and, as the force with which they scour away the bottoms of the bays depends on the height to which the water rises with each tide, the effect of tidal action is often much greater in the upper part of bays than at their mouths. Thus, the Bay of Funday, between Nova Scotia and New Brunswick, has a tide of about twenty feet at the mouth, while the water rises as much as sixty feet in the interior or innermost part of the bay. The result is that the tides cut away the rocks at the head of the bay with far more force than at the mouth.

In this way it comes about, that wherever there are strong tides, they tend to cut out and deepen the bays along the shore, by the ceaseless rushing of their waters. Shores with strong tides are in this way almost always much cut up into inlets that afford good harbors.

Some of the finest instances of tide-cutting are found along the British shores, where the tides are generally strong. The channel which separates Great Britain from France and Holland has doubtless been cut through by the tides. The mouth of the Thames and of the Severn have been greatly scoured out by the same action. The Chesapeake and Delaware Bays, on our own coast, are probably due to this cause. Wherever these old tidal bays are elevated above the sea-level, they appear as very broad valleys through which a stream flows. Gradually they are changed in shape until they look much like river valleys. For a long time the steep cliffs on either side show the action of the sea; but gradually these are worn down, and we can no longer tell that the valley was formed by the tides.

As the sea is constantly rising and falling along the lands, it is likely that the lower parts of all our large streams have had their shape in part determined by the tidal forces. We can see the marks of this work near the mouths of the Connecticut, Hudson, Delaware, and all the more northern rivers on the eastern shore of this continent, as well as the northern rivers of Europe.

This tidal force comes upon the earth from the attraction of the sun and moon on all the matter composing the earth. The land is too rigid to give way to the impulses, but the fluid waters swing in the broad waves of the tides.

These tidal waves produce only a few geological effects

of importance. Besides cutting out the bays along the shore, they, by their currents, carry a good deal of sediment from the shore, and lodge it on the bottom some distance out to sea, forming a broad under-water shelf along the coast.

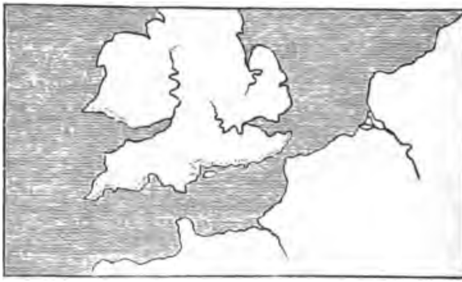


Fig. 61. **Channels carved out by Tides.**

The currents that the tides produce in every part of the oceans serve also to feed many forms of life that are fixed to the bottom of the sea, and, therefore, unable to seek their food. As the waters drift by them, on the tide, they can grasp it with their tentacles, and carry it to their mouths.

LESSON II.

LAKES.

Among the most beautiful features of the lands are the lakes. It is rather because of their beauty, than because they are very important features in the mechanism of the earth, that we shall give a brief account of them. They are very interesting to the student of nature, for the reason that they show many curious ways in which the forces of earth and air have worked to produce the form of the lands.

First, let us notice that lakes are very irregularly scattered over the earth's surface: there are certain regions, such as New England, where the land is sown with them; indeed, the whole of North America down to the latitude of about 40° abounds with them, while south of that region they are very rare, indeed; so that, while Massachusetts has several thousand, counting those above an acre in area, there are many Southern States that have hardly a single water basin that can fairly be called a lake.

Lakes are so different in their form that they have only one common character: they are basins containing water separated from the main seas, so that if there is any water connection at all with the ocean, it is by means of a river. We may divide these land water-basins into two great classes of salt lakes and fresh-water lakes. Nearly all lakes are fresh, but here and there we find basins containing very salt water. These salt lakes are always without any outlet into the sea; the reason they do not fill up the basins in which they lie, and overflow into the ocean, is that the streams that feed them cannot make head against the evaporation which the sun brings about, — their water

steams away into the clouds as fast as the rivers bring it in. If the rainfall of the region about our great American lakes should gradually diminish so that it would amount to only one-third of what it now is, the Niagara River would shrink gradually, and in the end no longer flow over the falls. Then the water in the basins of Lakes Erie, Huron, and Michigan would still further shrink until the evaporation from the remaining surface just equalled the amount the streams sent into their basins. In this shape their waters would slowly cease to be fresh, and in the course of ages they would become salter than the sea. This is brought about in the following way: Every stream flowing into the basin carries a little of the various salts that make the sea-water saline; when this water dries away in the basin, the salt is left behind, for such substances cannot go away with the watery vapor. The result is, the water finally comes to have more salt than it can hold, and this extra charge is laid down in crystals on the lake floor. This is the way in which the great beds of rock-salt have been formed, such as are found in many ancient rocks. Wherever these thick beds of rock-salt have been formed, we may know that the waters in the olden time have been completely evaporated by the sun; and this can only happen where basins of water are cut off from free connection with the sea-water through rivers that discharge their waters into the sea, such as those which drain all our fresh-water lakes.

Turning now to consider the ways in which the basins that contain lakes are formed, we perceive that they are made by different causes in different parts of the earth. In the regions north of 40° of north latitude, nearly all the lakes have had their basins cut out by the moving ice of the glacial time. The most of the lakes of New England have

been formed in this way, or are due to the dams of gravel and sand which the glacial streams have left across the valleys. The same is true of the lakes in Europe, even as far south as those of Italy. It is not easy to conceive just how the ice acted to dig out basins in the rock; but, if we examine the ground beneath a glacier, as we may do in many places, we find that the ice eats the soft rock away, leaving the harder; when the glacier disappears, the surface of rock is left with hollows upon it, which form little lakes, until they become filled up or have their boundary ridges cut through by streams.

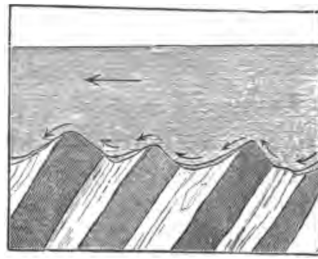


Fig. 62. Rock and Glacier.

When the great glacier of North America passed away, it left the surface with thousands of these rock basins upon it.

The greater part of them have become filled up, but many still remain open. Then the rubbish of the glacial period made dams across many hollows, or its surface was irregular, enclosing valleys in which lakes gathered, as is shown in the figures.

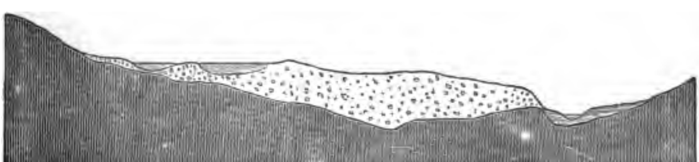


Fig. 63.
Moraine and Lakes.

The very irregular surface given to the land by the ice-action of a glacial period may be seen by looking at any of our northern shores from Boston to Greenland or in Scandinavia. We see that these shores are fringed with islands, and cut into innummerable bays. This is because the surface of the land has been made so irregular by the grinding of the ice. If the sea had made its shore in any part of the continent of North America north of the great lakes, it would have much the same irregularity of coast. On looking at a good atlas of the world, we notice that those northern shores which lie in regions ground over by the ice during the glacial period generally have these irregular shore-lines, while those of regions near the equator generally have straight coasts. Another way in which lakes are formed is this: A great part of our little-changed, stratified rocks are easily dissolved by water. Limestone beds, or beds containing rock-salt, etc., melt down and are dissolved by the long-continued action of water. We see how this comes about if we study the shores of such a basin as Lake Ontario: the waves beating against the shores break down and grind up the soft rocks; the lime and other easily dissolved substances mingle with the water and pass away to the sea; the quartz or sand-grains partly dissolve and in part are washed away into the deeper water of the lake. In this way, all our great lakes are increasing their surfaces and diminishing their depths.

Although this is rather more a means of enlarging than of creating lakes, it is likely that some of the great lakes of the world have originated by this dissolving action of waters acting on beds of rock-salt or other easily dissolved materials.

There is a third way in which lakes may be formed. When

the lands rise above the sea, they often have deep pockets or basins in them, which, when they are lifted above the sea-level, become lakes. If the rainfall of the country is large, these basins will have more water poured into them than can be evaporated by the sun; so they will flow over at the lowest part of their edge, and, in time, their salt water will be washed out of them, so that they will be fresh-water lakes. If, on the other hand, the rainfall is too small to fill the basin, then it shrinks to a lake without an outlet, such as the famous Dead Sea of Syria, or the Salt Lake of Utah.

In some cases the lake is formed by the rising of a mountain across the path of the stream; generally the mountain grows so slowly that the stream keeps its way open, but in some cases the mountain lifts too fast for this down-cutting of the river-bed to keep pace with the uplifting of the dam: then a lake is formed, which, in time, is drained by the deepening of the stream bed.

These seas of the land, however formed, are but temporary things; all over the lands we find the floors of drained lakes; they abound in the desert regions of the Rocky Mountains, in Switzerland, and elsewhere. We may look forward to the time when all the lakes that now exist will either be filled up by the rivers that flow into them, or drained by the cutting down of the beds of the streams that drain away their waters to the sea. But new glacial periods will doubtless create new basins, and others will be made by the dissolving of the rocks, or by the irregular rising of mountains or the lands; so that, as long as the world endures, these beautiful features of our landscapes will doubtless exist.

CHAPTER VII.

MOVEMENTS OF THE EARTH'S SURFACE.

LESSON I.

EARTHQUAKES.

FORTUNATELY for the life the earth bears upon it, its surface is generally so steady that it merits the name of *terra firma*, the firm-set earth, the ancients gave to it; yet at times this earth's surface is rudely shaken by those jars and tremblings we call earthquakes. It is doubtful if the reader has ever felt such a quake, because in the greater part of North America as well as Northern Europe they are very rare, and usually so slight as to escape notice; a little rattling of the window panes, or a slight swaying of things hung by cords from the ceiling, being all that commonly tells us that accidents may happen within the earth that disturb its usual quiet. But in other lands these shocks are much stronger, and produce the most widespread destruction of life and property.

The best way to get an idea of the power of such shocks is to take the history of some great earthquake, and see how it affected the country it ravaged. For this purpose we will take first the earthquake of 1755, which in good part destroyed the city of Lisbon, in Portugal; not because this is by any means the most violent or the most destructive to life of the many thousand great shocks that are

recorded, but because it shows the different sorts of accidents that may happen in such convulsions.

On the first of November, 1755, without any previous warning from the lighter shocks that often foretell the coming of a great earthquake, a noise as of loud thunder was heard within the earth, beneath Lisbon, and with it came a convulsion, which in a few minutes laid the larger part of the city in ruins. Out of a population of about two hundred thousand persons, over sixty thousand perished. Then, as often in great shocks, a portion of the city built on the hard rocks escaped the worst ravages of the earthquake, while the other portions, built on clay, were reduced to heaps of rubbish. Thousands of the people who had escaped from the falling buildings took refuge on a great marble quay, or landing place, on the banks of the river Tagus, where they were safe from the falling walls. Suddenly this immense structure went down below the waters, carrying the crowd of people with it. None of the bodies ever rose to the surface; and, when the place was sounded, very deep water was found to occupy the site where the quay had stood. To complete the work of destruction, there came another of the calamities that often attend earthquakes on the ocean's shore. The sea slowly retired for a long distance, so that, in an hour, parts of its bottom never uncovered before were bared. Then with a roar it came back, in a wave fifty feet in height, that swept over the ruins, giving a speedy death to many of those who had been imprisoned in the falling houses. The ships in the harbor, which had been saved from the evils of the earthquake itself, were dashed to pieces in this rush of waters.

Thus, in this earthquake, we have the three forms of danger which these calamities may bring to man: the shuddering movement of the ground, the engulfing of parts of

the surface in fissures or rents in the earth, and the forming of vast waves in the sea which roll in great floods into the streams.

This shock, though it did the most damage at Lisbon, and hence has received its name from that city, shook a portion of the earth's surface larger than four continents such as Europe. In Morocco, a town with over eight thousand people, is said to have sunk into the earth as suddenly as the quay at Lisbon. Even in Scotland the waters of the lakes swayed to and fro as the earth swung beneath them. The hot springs at Toeplitz, in Bohemia, ceased for awhile to flow, and then burst out again in torrents of discolored water, showing that the deeper part of the earth there had been strongly shaken. Far out at sea the ships felt the shock so strongly that their seams were opened, and the men were thrown down upon the decks. The disturbance of the ocean reached farther than the shock itself. The sea rolled in great waves on to the shores of Madeira, and even in the West Indies it rose twenty feet above its usual level. There can be no doubt that all the waters of the Atlantic north of the equator were swayed by the shock.

It is likely that in this earthquake more than one hundred thousand people perished outright, and that thousands died from the famines and pestilence that followed from it; so that in this convulsion more human beings perished than in any battle.

We will now turn to another earthquake which happened in the Island of Jamaica in 1692, which shows us certain other effects of these shocks which are not so evident in the Lisbon earthquake. This beautiful island was the seat of a prosperous colony which had a wealth and promise exceeding that of any English settlement in the New World.

To this prosperity the earthquake of 1692 struck a fatal blow. In this series of shocks the ground was swept to and fro in a succession of waves. On the ridges of the earth-waves cracks opened, and, as the wave rolled on, these fissures closed again. People were engulfed in these chasms: many disappeared entirely; others were thrown out again; yet others were left partly buried, but squeezed to death in the jaws of the fissures. The buildings over the water sunk down in a standing position into the sea, and were long visible, with their tops many feet below the surface. More than a square mile of land around the harbor of Port Royal was thus carried below the sea. The in-rush of the sea carried a frigate over the tops of buildings, and left it on the roofs far from the shore.

This ruin along the shore was equalled in the interior of the island; though, owing to the fact that there were no large towns, there the loss of life was not so great. The whole surface of the earth was so moved that the soil on the hillsides slid down into the valleys; the rivers ceased for a while to flow, they were so blocked by the landslides. When they broke through these masses of earth, they ran for days a tide of mud intermingled with timber from the land that had slid down into the streams. The lofty Blue Mountains, which the hour before were covered with verdure to their summits, were terribly shaken and rent by the convulsion. After the shock they appeared half bare from the landslides that had carried the soil into the valleys.

The United States, as before remarked, is mostly free from earthquakes. There are only four regions in it that have ever been visited by shocks of much violence. One of these is in New England; another, in the Mississippi Valley, just below the mouth of the Ohio; a third, on the coast of California; the fourth, in the eastern part of South Carolina.

In New England, there have been three pretty strong earthquakes: the first in 1685; the second in 1727; the third in 1755. Of these, the last two were very violent. That of 1727 lasted for several years, and principally affected the region near Newburyport, Mass. It was a very curious disturbance; for, while the shocks — of which some hundred were felt, in the course of four years — were at first violent, they soon became slight. The strange feature was that, with each, there came from the earth a wonderful thundering, or bellowing noise, loud enough to startle people from sleep, even when they had been long used to it. Many believed that it was the Evil One himself, raving in his empire beneath the earth, and threatening to burst it asunder in his rage. We shall consider the cause of this noise at a later point in this chapter.

In November, 1755, occurred the greatest earthquake that ever was felt in New England, since the white men came to the country. This came as a single strong shock, which was most violent at and near Boston, where it threw down a great many chimneys, and for a minute or so was so strong that people could not keep their feet. New England had then mostly wooden buildings, so that the destruction of property was small; but such a shock at this day would be very dangerous to life, and would cause a vast destruction of property. In that day, chimneys were about the only structures likely to be damaged by a moderately strong shock.

The Mississippi Valley has had but one great earthquake, a succession of shocks, which began in November, 1811, and lasted until 1813. The first of these quakes was so strong that it probably made more than half the continent tremble for some minutes. The shock was felt in Florida, New York, Michigan, and the West Indies.

Then came, from day to day, successive shocks, which constantly shook a less wide extent of country, until there were only a few square miles of land that trembled at the end of this time of trouble. The worst effects of the movement were felt in the region for one hundred miles south of the place where the Ohio River enters the Mississippi. In the first shock, large parts of this region sank down to the depth of several feet below the former level. Into these sunken lands, which occupied many hundreds of thousands of acres, the Mississippi poured its waters in such a flood, that for some hours it ceased to flow towards the gulf, but ran back towards its source. The ground opened in many places, spouting up jets of sand and water above the level of the forest. As the shocks went through the forests, the trees bent over and locked their tops into those of others, or beat their branches to pieces in mutual blows. The low, strong log cabins were shaken to pieces; and, to protect themselves from the constantly opening and closing fissures, the people cut down trees, so that they fell across the path of the rents, and on these bridges they built shelters, in which they lived for months before the ground became steadfast enough to be trusted again.

So great was the ruin of the land, that the government was compelled to help the people to find new homes in districts where the earthquake had not done such damage. To this day there remain many marks of this earthquake, though near three-quarters of a century have passed away. Reel Foot Lake and Obion Lake, large sheets of water, were formed at that time. Many of the trees which were standing on the submerged land still lift their blasted trunks above the water, or are visible below its surface.

The earthquakes of California have been numerous and violent. The only one that led to any destruction of life

occurred at Santa Barbara, in 1811, or at about the same time as the Mississippi Valley earthquake. There have been many dreadful shocks in Central America, but, as a whole, the continent of North America has fared better than any other of the great lands except, perhaps, Australia. The worst regions for earthquakes are found in the west and north border of South America, southern Italy, Asia Minor, and parts of Central Asia, parts of the East Indies, Japan, and in New Zealand; while in northern Europe, Australia, South Africa, and Brazil, they rarely happen. But every part of the earth is subject to slight shocks.

It was once supposed that there was some relation between earthquakes and volcanoes. This idea came from the fact that every volcano, while in activity, trembles with repeated shocks; sometimes it shudders for days and months. But there are many regions, as New England, where there are no volcanoes within a thousand miles, yet strong earthquakes here occurred.

In trying to understand the cause of earthquakes, we should first notice the theories that throw light on their nature. Experiment shows us that we can make small earthquakes by exploding gunpowder underground, or in any way jarring the earth, which are just like the great shocks in everything but their size. Careful study has shown us that all earthquakes are of the same nature as the jar we can give a table when we strike it a blow with a hammer or with the clenched hand. If we throw a stone into a pool of water, we see that a little wave rolls away in circular, ring-like wrinkles. This is something like an earthquake wave, only it moves very slowly, and an earthquake wave very rapidly. If we strike the head of a drum, a succession of waves flow through it. This is

more like an earthquake wave. If we strike the end of a long timber with a hammer, a person holding his hand on the other end feels a jarring motion come to him from the timber. This is exactly like an earthquake shock. In the pool, the drum, and the stick of timber, a wave flies through the body, but the wave differs in its character. In the pool, the wave is only on the surface of the water; but in the timber it is all through it; every particle of the timber strikes against every other. If we took a sphere of timber or of metal, and struck it in the middle, the waves would run through all parts of it, and give a jar over the whole surface. Now, an earthquake is a jar or wave of just this sort that moves through the earth. It may be made in any one of many ways. We have seen that the rocks under the surface are often pressed strongly together, as in the making of mountain ridges. As these ridges rise, the rocks slip over each other, making a jar, as when we drag a table over the floor; or they break, forming what are called faults, which we know cause jars and tremblings. When melted rock is thrown into fissures, forming dykes, the fractured rocks are struck as with a great hammer by the inrush of molten rock. When the steam and other matters that escape from a volcano force their way along underground, they cause the rocks to expand, and make sharp movements, like steam-pipes when the hot vapor is let into them. As this heat dies away, the rocks contract, as the steam-pipes do when the steam is shut off. In all these, and many other ways, the earth is subject to sudden blows that give us earthquakes. We will now see more closely how an earthquake behaves. Let us suppose that, in the diagram, the earthquake starts in some sudden blow at *a*, and runs in all directions to the surface of the earth, *b b b*; there will be many shocks from one jar;

just as, when we strike a drum-head, or twang a guitar-string, there will be many waves follow the one movement. These successive waves are indicated by the lines $c\ c'\ c''$, etc. Now, where a man is standing just over the shock, at c, it will come straight up beneath his feet, and, if it is strong, he will be thrown vertically up into the air, from a few inches to many feet in height. When he is standing at c' or c'', he will find his feet pulled forward, and his body will be thrown to the ground. If there are three buildings, one just over the shock, as at c, and the others at c' and c'', that at c will probably have its walls

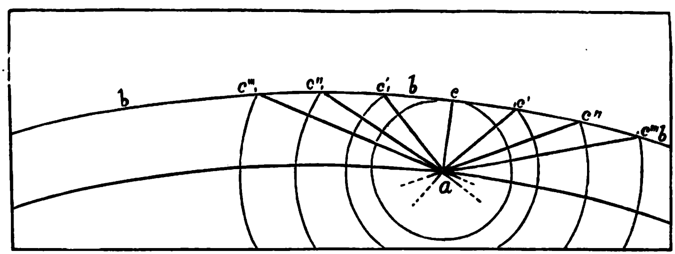


Fig. 64.
Diagram showing Earthquake Waves.

left standing, but the roof and floors will tumble into the cellar. Those at c' and c'' will have the walls that are at right angles with the shock thrown down, while the walls parallel to the line in which the shock runs will probably remain standing.

Just as the waves made by a splash in a pool run out, just as the jar given at one end of a long timber becomes feeble at the further end, so earthquake shocks wear out in running through the rocks of the earth. This causes the shocks to become more and more feeble as we get farther away from the place where they start.

On the land, the effects of an earthquake shock are very great; but in the sea they are even greater. The shock kills many animals in the sea. We often find the sea, near where a great earthquake has happened, covered with dead fishes, which have been killed by the blow they received through the water. We can imitate this by exploding a small charge of dynamite below the surface. The blow it gives is just like that which comes through an earthquake. This blow also seems to stir up the mud of the sea-floor, and this mud kills many animals. Then the earthquake lifts the surface of the sea over the place where the shock starts, and a wave rolls away from this place which may be strong enough to cross the widest oceans, and often rolls on the land in a prodigious breaker sixty feet or more in height. It is this wave that so often sends ships far inland, as in the earthquakes of Lisbon and Jamaica. In the earthquake of 1746, which ravaged the west coast of South America, a Portuguese man-of-mar was carried for a distance of three miles inland, and left stranded, though but little injured. Within twenty-five years, several vessels have met with this strange fate. This great wave, though without power to harm the life of the deep seas, is very destructive to all the creatures that live on the shores, grinding them up, and mingling them with the mud.

When we look over the history of earthquakes, they seem like very cruel agents of destruction. Next to battles and famines, they are the greatest life-destroying accidents that can befall man; and, among the lower animals, they are, perhaps, more destructive than any other sudden convulsion of nature. But, when we consider how slight and seldom are the shocks of great destructive power, compared with the great work of lift-

ing mountains, forming volcanoes, and otherwise maintaining the activities of the earth, we must regard them as very trifling accidents, and rather wonder at the slightness of their effects than regard them as unnecessary convulsions. Everywhere, and at all times in the world, we see such destruction of individual life; yet the life as a whole goes onward and upwards as steadily as if no death came about from the working of the great machinery of the earth. The Power that rules the world evidently does not regard death as an evil to be avoided; everything is made quickly to die, that better life may follow it; and, if we accept death as in the order of nature, the destruction of life by earthquakes, volcanic outbreaks, storms, and all the other violences of the earth need not shake our faith in the merciful plan of all things.

City ruined by Earthquake, with Landslides.

LESSON II.

CHANGES IN THE SHAPE OF SEA AND LAND.

ALTHOUGH the continents are the very firmest thing we know in nature, although there have been no great changes in the shape of land and sea since the earliest human history, we must not suppose that the lands endure very long in one shape. We know that in the long ages of the past very great changes have come over them. All the rocks that we know in the world have, except possibly some of those thrown out by volcanoes, been formed on the bottom of the sea, which is in itself enough to prove that all our present lands have been sea-floors. We find fossil sea-shells on the tops of our highest mountains, and there is hardly a place in the world where we are more than a few miles from rocks containing the remains of some animals that have lived on the sea-floor.

The changes in the shape of the land take place so slowly that we cannot recognize many of them within the time of human history; yet, along one coast, which has been known for some hundreds of years, viz., that of Sweden and Norway, the shore is in places rising as fast as three feet in one hundred years. On the west shore of South America, during the great earthquake of 1822, the shore for some hundreds of miles rose suddenly by four feet or more. Many other cases of such changes could be mentioned, but they only show us how slowly accumulated modifications can affect great changes. A few such lifts as that on the Chilian shore would greatly alter the form of a continent, especially if they took place on a shore along which the water was not very deep.

Besides these alterations that come from the up-lifting or down-sinking of the lands, there are slower-going changes; due to the wear of the sea and of the rivers. The water that falls on the country drained by the Mississippi wears away about one foot of its rocks in every seven thousand years, and bears the waste into the sea to form new rocks on the sea-floor. Taking all the river-basins of the world, or, in other words, about all the surface of the land, we have an average down-wear of about one foot in three or four thousand years. This seems slow; yet, when we consider that in the life of the earth a thousand years is but as a day, or, better, an hour in our own lives, it is really a rapid wear.

Then the sea too does its work of calling back the lands to its depths. Beating against the shore, it undermines cliffs and grinds their fragments to powder, which the currents easily bear away into the depths. When the coast is not faced with very hard rocks, it often cuts back at the rate of several feet a year. In England, for instance, whole townships, that once bore many villages, now lie buried beneath the sea.

This work of wearing away the rocks is mainly due to the action of the sun's heat. It sets in motion the winds that raise the sea waves, and it fills the winds with water that falls as rain; but, though it is a work of destruction, it is also a work of preparation for lands that are in time perhaps to be lifted above the sea in their turn to bear life. The most important effects of these changes of the lands are found in their action on the destruction of life over the earth, and in the course of the sea-currents, those great carriers of heat from one part of the earth's surface to another. We can best understand these effects by considering what would happen if the Isthmus of Darien,

which is but a slender, low bit of land, were to be deeply submerged beneath the sea. The animals now living in the sea-waters on either side of this isthmus are very different from each other, hardly a species being found both in the Caribbean Sea and in the Pacific Ocean. If the isthmus were buried beneath the sea, these animals of the two seas would be brought into contention with each other. Many animals now limited to the Atlantic waters would extend into the Pacific, and many unknown in the Atlantic would destroy those from the Pacific waters. Many of the weaker kinds would be destroyed by their stronger enemies, and in a few years the life in either ocean near the isthmus would be greatly changed.

If the down-sinking in the Central American district were carried so far as to lower the northern part of South America beneath the sea, converting it either into open water or into an archipelago, then the great current that becomes the Gulf Stream would no longer flow into the northern Atlantic, but would pass through this gap into the Pacific Ocean. The result of this would be that northern Europe and the most of the United States would become too cold for the life of man, while the tropical regions would have their heat increased. This instance will give an idea of the effects that may come from lowering lands beneath the sea.

Now let us turn to Asia, and imagine what would be the effect if the string of islands, that nearly connect that continent with Australia, were to rise higher above the sea, so that the two continents were connected by a continuous land bridge. In this case the effects would be these, viz.: the currents of warm water that now pass from the Pacific Ocean to the Indian Ocean, through the straits between these islands, would, when barred out from the Indian

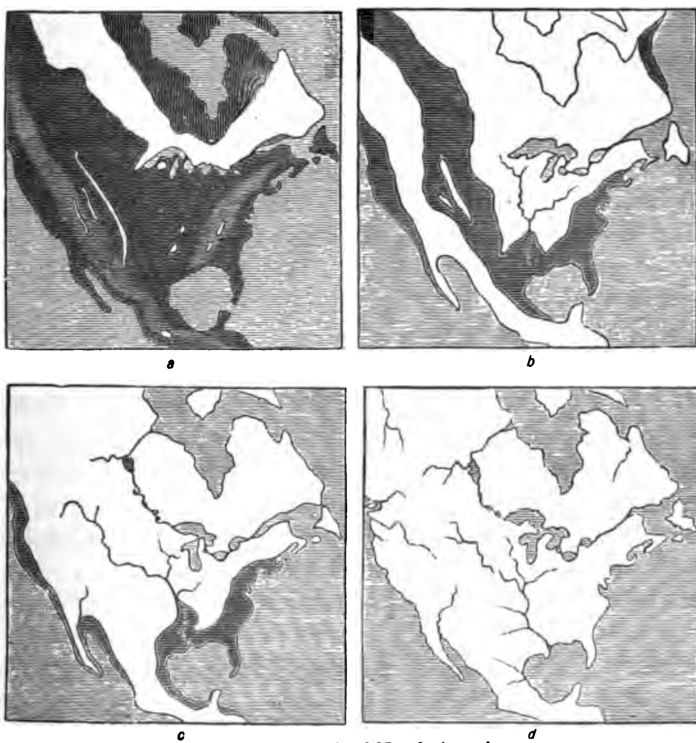
Ocean, turn northward and southward towards either pole, carrying more warmth to the cold regions of the earth and diminishing the heat of the tropics. The continent of Australia has hardly any quadrupeds except creatures akin to our opossums, such as the kangaroos and the like, animals that carry their young about in pouches. Of these animals, there are over one hundred species living on that land. All these creatures are much weaker than the quadrupeds of Asia. As soon as this bridge across to Asia were formed, the tigers, leopards, and other beasts of prey would pass south to *Australia*, and quickly exterminate the kangaroo tribe, while their place would be taken by the stronger or fleeter-footed elephants, buffaloes, and deer from Asia.

We know very well that just such changes of level of sea and land as we have imagined to occur in these isthmuses and archipelagoes of America and Asia have very often happened in the history of the earth, so it is fair to presume that they may happen in the future.

It is hard to conceive this constant up-rising and down-sinking of the shore; but, if we will consider the matter, we shall see how it must often happen. The shrinking of the earth's interior, from the constant cooling, is constantly causing its surface to wrinkle, deepening the sea-troughs and lifting the lands into the air. The rivers, the sea-waves and the tides are always cutting the land down to the sea level. Broad surfaces of the sea-floor in the great oceans are sometimes sinking, which serves to draw the water away from the other seas, lowering the level of the shores: again they are rising, causing the waters to rise along all the sea-coasts in the world. When a glacial period comes, a great deal of the water which now is in the seas is taken out and heaped as ice on the land

about the poles, and this lowers the level of the sea; when the glaciers melt, this water is returned to the deep, raising its level again. Thus we see that there are abundant reasons for a change in the height of the sea along the lands.

These changes do not seem ever to destroy any of the continents. From time to time their shapes change, but the greater lands seem to have been constantly growing ever since the earliest times in the earth's history.



Stages of Growth of North America.

CHAPTER VIII.

THE PLACE OF ANIMATED THINGS IN THE WORLD.

LESSON I.

THE WORK OF LIFE ON THE EARTH.

AT first sight, it may not seem to the reader that the animals and plants of the world have any very close relation to its structure,—that they have any sufficient claim to our attention when we are considering the geological history of our earth. This, indeed, was the old way of looking at the realm of animated nature; but, the more we know of the earth's life, the more clearly we perceive that this life, both inorganic and organic, is so bound up together that it is all one in its work.

The life of the world came out of the earth by laws which we do not understand. Every creature exists by fitting itself to the physical forces about it, and when it dies its dust goes back to the soil. As far as its bodily parts are concerned, each creature in the world is but a bit of earth that has become for the moment filled with the forces of life. All the work of its body is determined by laws of the earth's matter from which its body is formed, and of which it always remains a part.

The force that impels these animated things is derived from their food; which, in the plants, is either the mineral matter of the soil and the carbon in the air, or, in the case of the animals, it is the vegetable kingdom that sup-

plies the food directly in the herbivora, or at second hand, as in the carnivora. This force is given to the plants by the action of the sun's heat; by it the plants separate the carbon from the atmosphere, and build into their bodies the mineral substances obtained through their roots. These things the plants consume, and obtain thereby the solar force that the plants built into their structures. In this way we may say that plants, and the animals which they support, owe their life to the same force that sets the winds or the rivers in motion.

We should notice, also, that the animal and vegetable life of the world plays a very large part in the working of the earth's machinery. The land plants protect the lands from the rain, which would rapidly wear away their surfaces but for the covering the plants afford. The carbonic acid which these decaying plants furnish to the water give it a great power of dissolving substances of many kinds, and so aids in the formation of mineral deposits and the excavation of caves, as we have already seen. Plants and animals furnish a vast deal of material for the formation of rocks. More than half the rocks on the earth's surface owe their formation, in whole or in part, to the action of animal or plant life. All our coals, bituminous slates, and limestones are essentially the work of the living things of past times, and the greater part of our sandstones and other rocks are partly their work.

We should also see that the greatest work of the earth, from ancient ages, has been to afford the place on which, as on a theatre, this life has played its part. We find the most wonderful proof of the earth's perfection in the fact that for a time, so long that our imaginations are too weak to consider it, it has been so well ordered that no convulsions have prevented the animals and plants from

steadily going forward in their development. Ten miles beneath the surface, there is a heat so great that no life could bear it; ten miles above, a cold so intense that, if it should come to the earth, nearly all created things would immediately die. Yet for ages the balance has been so preserved, and the temperature of the earth has remained so near what it is at present, that these sensitive living creatures have not been killed, but have prospered from age to age.

In this way we perceive the intimate relations between life and the world it inhabits; we see that even the brief and general view of the earth which we are now taking would be too incomplete without at least a glance at the history of animals and plants.

LESSON II.

DIFFERENCE AND RELATIONS AMONG LIVING BEINGS.

WHEN we look around on the beings that make up the kingdom of animated things, — the plants and animals of the world, — we easily see that they are in many ways akin to each other. First, we see that they all have some common qualities. They are alive, they grow, they reproduce their kind, and in due time they die, — actions which separate them widely from the mineral kingdom. Then we see that the animals are pretty distinctly separated from the plants by the fact that besides their life, growth, etc., features which are common to both, animals have sensations, and show even in the lowest forms signs of something like will in their motions.

Among animals, we notice a great many different degrees of kinship. We see, for instance, that all our common four-footed animals are akin to each other. Bulls, sheep, deer, and other horned animals are closer related to each other than they are to pigs, elephants, or horses. Crayfishes, lobsters, spiders, and insects are evidently, by their outside jointed structure, more like each other than they are to our back-boned animals. If we compare our own bodies with the lower animals, we see at once that our nearest animal kindred are among the ordinary quadrupeds. This matter of relationship may be by study carried much further, for we find that all animals are related to one another in varying degrees. A great part of the study that naturalists have given to living things has had for its object the determining of those relations that exist among them. The result is that we find that these relationships may be expressed

by what is called a system of classification. At first sight, this scheme of classification looks very complicated; but, if we look at it carefully, we see that it rests on very simple principles. A clear understanding of these principles may be had, if we take some other objects than animals and plants, and apply a system of classification to them.

For this illustration, let us take the contrivances made by man for measuring time. There have been many different plans of accomplishing this end, which rest on the following plans of working. First, we have the ancient water clocks, where time was measured by allowing water to drop out of a vessel through a small hole. A familiar instance of this mechanism is the sand-glass, where sand, slipping through a narrow opening, measures the time. In these there is the common plan of having some particles of water or sand slip through a hole under the influence of the earth's attraction. They differ in the way of carrying out the plans in the two machines; or, we may say that there is one plan of structure in these machines, and two divisions, which we may conveniently term classes of structure under the plan. Then we have the sun-dials, where there is a very different plan, and two classes of methods of carrying out the plan. One, when the gnomon, or part that casts the shadow, is fixed; another, when it is attached to a magnetic compass, so that it may set itself at any time. Examining the structure of fixed dials, we find that sometimes they are horizontal, sometimes vertical, as in those that are placed against a wall. To these divisions we may, as before, give any name we choose, but for convenience we may term them orders under the class of fixed dials. Looking more closely at these dials, we find yet further differences under each,—some of the horizontal dials are set up in columns, and some are placed on the

pavement. These differences we may, for convenience, term families under the order of horizontal fixed dials. We may go still further in our division. In some cases, we see that the figures denoting the hours are printed on the dial; in other cases, they are cut into its substance. These differences we may denote by the name genus, and we would make two genera of dials in each of the two families. By careful study, we should find that many such genera could be made. Finally, our examination brings us to groups of sun-dials which are all so alike that we cannot perceive any constant differences among them. They are of about the same size, shape, color, etc. We may even suppose that they came from the same factory. These groups we will term species.

We can take the same course with the other and more varied plan of time-measurers, — clocks and watches. We shall find these classes, orders, families, genera, and species just as we have seen that they exist in sun-dials, only it takes more time and more study of their mechanism to make them out.

This system of classification can be applied to a great many other structures; indeed, to all forms of human contrivances where men have made many inventions all working towards one result. The reader can see that in instruments for aiding locomotion, such as ships, wagons, balloons, etc., or in contrivances for giving power, such as windmills, steam mills, water mills, etc., or implements of war, such as armor, arms, javelins, spears, swords, guns, etc., the same system of classification can be made. It will be more profitable for the reader to work these out for himself than for them to be described here; for the only aim of this classification of human products is to show the principle of the classification which is applied to natural objects, which otherwise is hard to understand.

When we apply this principle of defining relationship or likeness, according to its degrees, to animals and plants, we find that it leads us to essentially the same result as when it is applied to human contrivances. There is always something like a plan which naturalists sometimes call a *type;* different ways in which the plan is carried out, called *classes;* peculiar complications of it, termed *orders;* under these orders, variations of the general shape to suit different conditions, called *families;* still other subordinate divisions, based on details of structure, called *genera;* and finally, the last division that we can make, which is commonly termed a *species*. All these divisions rest upon differences in the ways in which animals adapt themselves, by their peculiarities, to the needs of their life.

Among animals these divisions are clearer and more numerous than among plants, for the reason that animals have more definite and numerous results which they seek to attain than have the plants.

Among animals, naturalists recognize several different plans of structure. The differences are in the general ways in which the animals are built. These differences may be compared to the various sorts of time-keepers. In time-keepers there is one object, viz., to divide time into intervals; but, among animals, the creatures must do a number of tasks: they must nourish themselves, protect themselves from enemies, reproduce their kind,— all of which the plants do as well,—but above all they must have some mechanism of sensation, some fitness for the work of intelligence, however low that intelligence may be.

These plans of building animal structures for their many uses are five or six in number. The protozoa, the radiates,—which group is sometimes divided into two,—

the articulates, the mollusks, and the vertebrates. Some naturalists have made more than these divisions, but those given above are the most clearly to be seen. In each of these groups there are two or more classes; in each class several orders; in each order many families; and under each family many genera; under each genus many species are ranged. It is not possible for us to trace these divisions here,—that would be a great task,—but only to give the reader some idea of the nature of the classification among animals, for that has often to be set before the mind of any one who considers organized beings. To make the matter clearer, we will consider the way in which a naturalist looks at an animal when he is classifying it. For this purpose we will take a common honey-bee as an example of the work.

First, we notice that the bee is a member of the organic kingdom, because it has, in common with the other animals and plants, the powers of nutrition, growth, reproduction, etc.,—qualities that belong to all this group of natural objects. *Second*, that it belongs to the group of animals, because it has the means of perceiving sensations, and a share of that quality of mind that separates all animals from plants. *Third*, that it is an articulate animal, because its body is built on the plan of many ring-like segments placed one behind the other, like the worms, lobsters, or cray-fishes. *Fourth*, that it belongs to the class of insects, because, in common with all the insects, it has three pairs of jointed legs, each pair belonging to one of the middle segments of the body, a separate movable head, and an abdomen divided from the parts that bear the legs. *Fifth*, it belongs to that particular group of the insects called hymenoptera or membranous wings, because it has four wings, not covered with scales,

as in the group of butterflies, but made of an easily-folded, cloth-like substance, as well as certain peculiarities of the jaws which fit them for very varied work. *Sixth*, it belongs to the special family of bees, and is separated from the wasps, the saw-flies, and the ants, by its peculiar solid, compact form, which enables us in a moment to see that all the bees belong together. *Seventh*, it belongs to the genus of bees, because of the special structures about the mouth, etc., which are not present in other members of the family. *Eighth* and last, it belongs to the honey-bee species, because it has the precise form, the color, and the habits that mark its kindred. Thus, by eight steps of division, we place this creature so as to show the greater differences between itself and the other living things. This process we take in classification with any animal or plant.

CHAPTER IX.

A SKETCH OF THE EARTH'S ORGANIC LIFE.

LESSON I.

LINES OF ADVANCE IN ORGANIC CREATURES.

WE have already glanced at a part of the machinery by which the earth carries on its physical life. We have been able to look only at the merest outlines of this work. Yet we have seen that the earth is not a place where mere accidents contend against others, but that its physical work goes on with a stately order; that even its most violent activities, the volcano, the earthquake, the lifting of the lands from the sea, and the mountains upon the land, are all so accomplished that the alteration does not break the harmony of the whole work, but rather contributes to its perfection. We have now to consider the second and higher form of the earth's life, — that which exists in things which we call living, — in animals and plants. The lower or physical life of the earth shows us matter in the control of laws that shape it into the lands, the mountains, in sea or air, but leaves it without sensibility, without power to renew itself. Mountains or crystals, and other inanimate things are brought to their shape and pass away into the waters without helping themselves in any way. In this regard they are in strong contrast with living beings. All plants and animals grow from within themselves by processes that make

them living. They can all multiply their kind. In these respects they are strongly contrasted with all the so-called lifeless part of the earth, which, though in a true sense living, exists in other ways. Every animal and every plant feeds in some way or other; it can take in the matter from the world outside of its body, and by changing the chemical shape of this matter it can accomplish two ends: it can take the matter itself, to build its body or to reproduce its kind, and it can take the force that exists in the matter, and use it for its own purposes, — to move its body with, or to carry on the circulation of its blood, or any other of many uses. In this they may be compared with a steam engine. For instance, when plants take in carbonic dioxide, which consists of one part of carbon and two parts of oxygen bound together, they separate the two elements, build the carbon into their bodies, and throw the oxygen into the air. To effect this change, they make use of the light and heat of the sun; for it takes a certain amount of force to separate these two elements. When an animal eats the plant, it burns part of this carbon in its lungs, by bringing it in contact with the air, and thereby gets a good deal of force to use in the various movements of its body. It is this power of taking a force from the outside world, and using it to sustain all sorts of activities, that separates the animal and vegetable world from the lower life of the earth, and makes them a kingdom by themselves. Because of this peculiarity, there can be no passage from the mineral to the living world.

Animals and plants appear to have begun in a very ancient stage of the earth's history; we do not know just where, when, or how the beginnings were made; for the ancient history of life has been lost to us, through the

changes that the rocks have undergone, which have destroyed all the fossils they ever may have contained. These earliest forms were doubtless of a very simple structure.

The lowest organized beings we know have many of the features both of animals and plants. They are little bits of a jelly-like substance, having no distinct form, no parts of the body adapted to any special uses, such as eating, digesting, motion, etc., as have our higher animals. From some such simple foundation of life all beings seem to have sprung, through the action of laws that we do not yet fully understand. We can see one kind coming after the

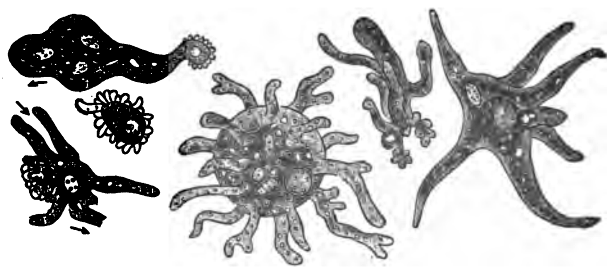


Fig. 65. Rhizopods.

other and out of the other, as we go through the records of the rocks from the earliest days to the present time, but we cannot see just how the change from one kind to another is effected. Very early in the history of the world, it is clear that these two kinds of beings, plants and animals, were begun.

The lower plants were probably seaweeds. The plan on which their structure was built made beings suited for taking carbonic dioxide gas out of the sea-water, which contains a little of this gas, and for building its carbon into the body of the creature. They also took a number

of other substances from the water. There were in them no roots, and they differed from distinct animals in having no arrangement for sensation. This is the really strong difference between animals and plants. Plants work to make structures that get along without any sensations, while animals, from the first, and always, provide for this work of receiving impressions from the outer world. Animals, even the lowest, also have means of making voluntary movements, which either help them in feeding alone, or, when they are not fixed as by a stem to some solid body, enables them to move about at will. Some low plants, and the seed of many plants, have means of moving that at first sight look like those of animals; but they are plainly involuntary organs, and not connected with any capacity of recurring nervous sensations nor to be compared with the motive parts of true animals.

When, from the lowest forms of these beings we pass upward to the higher, we find that in plants the following objects are sought to be accomplished. The structure is arranged so as to give a solid stem and branches, and to contain many separate individuals in one community. The work of leaves is separated from the rest of the plant, and the roots are inverted, which enable the plant to draw a certain share of its nourishment from the ground. Especially, it can find water there, which would often be unattainable in the air. While the plants remain water creatures, they do not need their roots; it is only when they come to dwell on the land that their roots become developed. In the water they found all they needed for their life without these appliances.

These steps lead us up from the simplest seaweeds, which have nothing that we can fairly call leaves, stems, or roots, through the higher seaweeds, where the stem becomes dis-

tinct from the leaves, through the mosses and lichens, the ferns, the palms, the pines, to our oaks and other familiar trees.

In this succession of forms, the plant contrives to separate its parts into the roots, that gather food from the soil, the stem, which supports the upper part of the body

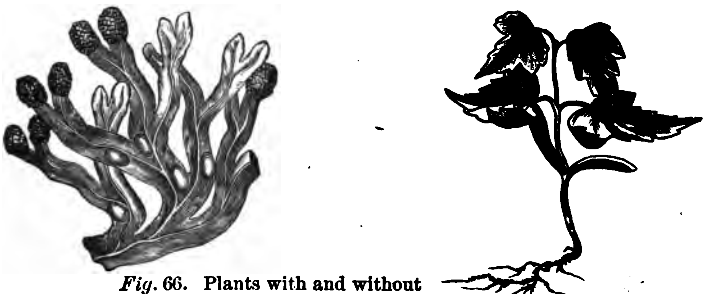


Fig. 66. Plants with and without Roots and Stems.

and keeps a connection with the root, and the branches which support the leaves and flowers. At first, the stem and branches have no distinct bark, and they grow by additions made throughout the mass of the wood; but in

Fig. 67. Endogens and Exogens.

time they devise a way of growing only on the out or bark side, the inner part of stem and branches being very solid, so as to serve for support, while the sap is carried in

the bark alone, and the solid central wood forms a better support. This contrivance enables the plants to have smaller, stronger branches, and their trunks can carry more top burden of twigs and leaves.

In its perfected form, the tree consists of many separate individuals, — the buds, united together by their common property, the branches and trunk, while the roots below do the work of separating the mineral substances from the water that dissolves them, bearing them in the sap up to the leaves.

But the changes that take place in the general form of the plant are only a small part of the whole change that occurs in the ascent from the lower to the higher. These are so numerous that we will not try to trace them. There is only one other that needs our attention. In the lower kind, we have only one individual in one plant. As we go higher, many individuals come to be associated together, as in our common trees. An oak, for example, is really an association of many different plants, each bud being a distinct plant, all of them uniting in the work of building the stem, branches, and roots, which are the common property of the association. This careful bringing together of many distinct individuals in one community is a peculiarity of the higher plants.

Fig. 68. Single and Compound Plants.

These changes have for their purpose the better life of the individual plant. There are others, and more important, which are contrived for the good of the seed. The

lowest plants have very small and simple seeds, and nothing that can fairly be called a flower. The spores, as these tiniest forms of seeds are called, are very small and very numerous. They are made on the leaves, as in the ferns. In this state, the seed has life alone given it by the parent plant. No food is stored with the germ. In the higher plants, there is a distinct flower, made up of a number of leaves that have changed their shape to make the parts of the blossom. This flower develops seeds of a higher structure than those of the lower plants. Around the life-containing germ is gathered a supply of starch and other food intended to support the young plant in its earliest stages of growth. In this way, the parent gives something of its strength to help the offspring in its period of infancy.

These changes from the lower to the higher plants are slowly worked out in the course of the long ages of the earth's history. Plants do not move upward in their structure with the same speed as the animals; still they have advanced age by age, and finally give us our flowers and fruits. The flowers and fruits are offerings the plants make to the insects, birds, and other animals in order to get their help in the work of fertilizing their seed, and conveying them to places where they may grow. To fertilize a seed in the best way, it is necessary to carry the pollen of one plant to the pistil of the flower that grows on another plant. This is done by the insects. They are attracted by the gay flowers and sweet odors of the plants, and are paid for their labor by the honey and pollen they get by their visits. They go smeared with the pollen from plant to plant, and thus, without intending it, fertilize the seed in the way best suited to their needs. The fruit, by its sweetness, and the seeds, by their nourishment, tempt the

birds and beasts to eat them, and in this way they are carried about and dropped in places which will give them a chance to grow to advantage. Other seeds, which have hooks upon them, are arranged so as to catch on the fur of animals, and so are carried about until they fall far away from the parent plant.

There are many other ways in which the plants seek the help of the animal world; but these few examples will serve to show us how closely knit together are these two kingdoms of life, how they reckon on each other for help in the struggle for existence. In this work, the plants give far more than they receive. They give to animals all their food, for there are no forms of animal life that can take food directly from the mineral world. All must come to them through the plant. In exchange, they receive from the animals only a little help in the fertilizing and the carriage of their seeds. Even this they pay for with their honey, the sweetness of their fruits, or the nutrition of their seed, so that really the plant world gives everything and receives but a trifling recompense.

The animal kingdom has an altogether different set of purposes from the plants. The animal form appears to be striving to make itself more and more fitted to be the habitation of intelligence. For this purpose, it needs to be very different from the plant. It needs, in the first place, to have a system that shall serve for the reception of sensations, for the seat of the intelligence, and the giving of the commands of the intelligence. This is accomplished by the making of the nervous system, the machinery of intelligence, which slowly, as we go higher and higher, takes on a more and more perfect character, with eyes, ears, the power of taste, smell, etc., to give communication between the intelligence and the outer world.

Then the animal, to be a fit seat for intelligence, needs a variety of parts that shall obey the will, organs for grasping, for motion through the water or air, or over the earth. All this is brought about by the limbs in their many various shapes, under the intellectual control.

LESSON II.

PROTOZOA AND RADIATES.

THE lines of advance among animals are not made in one ascending path, as they are among the plants. There are at least four great groups of animals, each of which takes its own proper line in the effort to work out the problem of how to build a structure fitted for the uses of intelligence. Most naturalists, indeed, consider that there are five of these lines of advance. The lowest of these five is the protozoa, or animals of lowly life; the simplest of

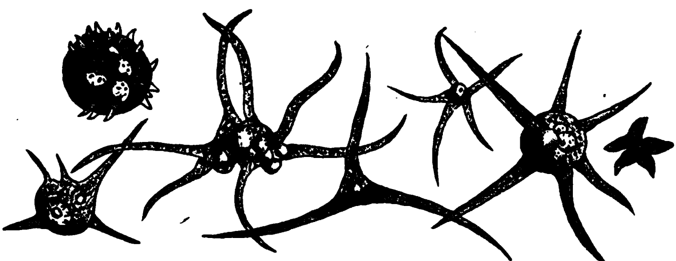


Fig. 69. Rhizopods.

these creatures generally appear to us as mere masses of jelly, that have no distinct mouth or stomach, and no regular organs for moving the body. They do not lay eggs, but increase in numbers by dividing the mass of the body, each part being able to set up life for itself. These forms are all very small,—the most of them, indeed, microscopic in size; they are generally transparent; sometimes they are as easy to see through as a bit of jelly. Yet it will not do to be too certain of their simplicity, for the reason that, though appearing so little complicated, they often build structures of the greatest beauty and symmetry.

Many species of these protozoa assemble themselves in communities, resembling the communities of individuals that make up an oak or a pine tree; such, for instance, are the sponges, which are each made by myriads of animals that grow together, and by uniting their work, build a mass many thousand times as large as the individual animals. They all dwell in the water.

Higher in the scale than the protozoa stand the radiates; these are generally star-like in form; each ray of the star is made up of a set of parts; in the middle is a mouth and stomach, which do the work for all the rays. This star-like order of parts is much like what we have in the

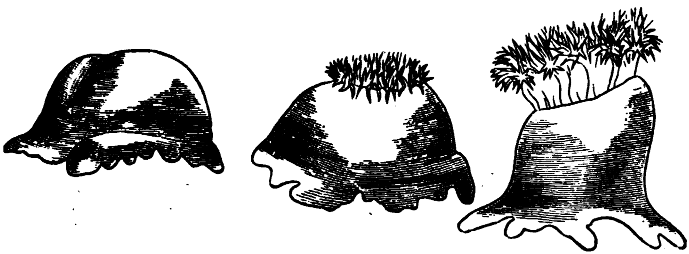


Fig. 70. Sea Anemones, closed and partly opened, akin to Corals.

plants, which generally show something of a star-like arrangement of parts. They are all water animals.

The lowest radiates are the corals and jelly-fishes; these creatures generally are grouped together in communities, many thousands working to build a common support. This gives them great strength; while, if separated, they would be very weak animals, quite at the mercy of the waves.

The next higher radiates, the crinoids, are also usually attached to the bottom of the sea; but they are much larger creatures, and encased in a solid shell, which stands

up on a flexible stem. They are no longer such simple forms as their lower kinsmen, the corals.

Fig. 71. Sea Lily.

Next higher, we have the star-fishes, which are the first animals that can crawl by means of something like feet. They have suckers coming from one side of the arms, that enable them to move along the bottom with some ease. Still the direction of their movement is not determined; they move quite as easily one way as another. Having nothing like a head, they have no need of a definite direction of movement.

Then we have the sea-eggs or echini, where the animal is condensed into a sphere-like form; and in the highest of

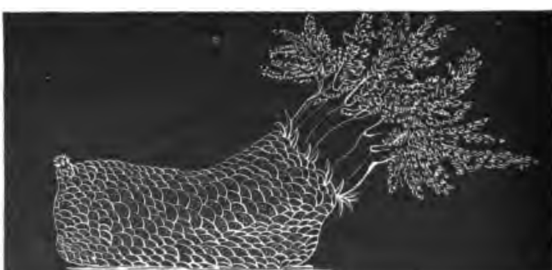


Fig. 72. Holothurian.

these radiate animals we find, for the first, an animal that moves in a definite direction. Although various animals of lower structure move, it is first in the echini that we have this motion fixed in its direction. The creature does all in its power to twist the body into such a shape that the mouth may come at the front end of the body; but

the way in which it is built makes this a very difficult thing to do. Finally, in the sea-cucumbers, or the holothurians, the creature is turned over so that it walks on its side; in this way it manages to use two of its bands of suckers as limbs, and the mouth is brought at the advancing end of the animal. These radiates give us the first series of efforts to build a structure fitted for the uses of intelligence; the only structures out of which they could build limbs were the soft suckers on the arms and the stiff spines; they do all that can be done with them, but they are not well fitted for this work of motion; besides, the radiate plan of the body is better suited for a fixed than for a movable form, as we see from the fact that plants are generally radiate in form. It requires a great deal of time for these simple experiments of radiated animals to be carried through to their half-successful end. The radiates

Fig. 73. Star-fish.

are among the earliest animals known to us, and it is not until near the present day that all these experiments in locomotion had been tried. The nervous system on which more than anything else the fitness of the body for the uses of the mind depends, is not even at the end well developed in the radiates; yet it deserves to be remembered that this system did actually begin in this group, and is carried to a certain state of completeness. We find traces of it in the jelly-fishes, and it is best shown in the sea-eggs (echini) and the sea-cucumbers (holothurians). It is, however, not to be compared with the perfection of the same system in the higher forms of the other higher groups of animals, as we shall shortly see

LESSON III.

THE MOLLUSKS.

THE next great group of animals above the radiates is the mollusks, familiarly known to us in our oysters, clams, slugs, snails, squids, cuttle-fishes, etc. This group differs widely from the radiates in the plan on which the body is built. In the radiates, similar parts are arranged about a centre of growth, where the mouth and stomach are situated; in the mollusks, the parts are placed on either side of a plane that extends from the front to the rear end of the body. The mouth is at the anterior end of this line. This arrangement of parts is just what is needed in the animal body; it makes motion possible; and in this motion the head can go foremost. The nervous system in the mollusks is better built than in the radiates. It exists even in the lowest forms, and attains a high grade of perfection in the highest creatures of this group, the squids, which are really very perfectly adapted to the uses of intelligence. The simplest mollusks are akin to our clams and oysters. In the lowest, the creature has but slight power of motion, often being fixed to the bottom by the shell or by a sort of rope the animal spins. The higher forms, like our hard shells or the fresh-water clams, are able to move by means of a flesh projection called the foot, that can be pushed outside of the shell, and used in crawling, like the foot of a slug or snail. Our fresh-water clams or unios can travel at the rate of something like fifty feet an hour. This is the most successful walking that has been attained in the animal kingdom up to this level of structure.

When we come to the single-shelled mollusks, such as snails and their kindred, we have the power of motion more constant than in the bivalve-shelled mollusks. Nearly all of them can crawl. Besides these, we now

Fig. 74. Common Clam, with siphon protruded.

have something like a head to the animal. There are structures that do the work of eyes, and feelers that serve for the sense of touch, and perhaps organs that convey the sense of hearing, all gathered about the front end of the body.

Fig. 75. Sea Snail.

This group of snail-like, single-shelled gasteropod mollusks is also interesting for the fact that it gives us the lowest animals that are able to live upon the land. All the forms of animal life below this level are limited to the

water. There are several reasons why the lower mollusks cannot come upon the land. Their bodies are all very soft, and have no skin to keep the water from evaporating in the air. Then, except some of the bivalve shells, they have no organs for creeping. When they move at all, they only float in the water, helping themselves a little, as the jelly-fish does, by flapping the projections of the body.

The snails and slugs can live and move on the land because they have a closer skin, that keeps them from drying up so fast, and a foot for crawling; and they are fitted for breathing air by having air-sacks in place of gills.

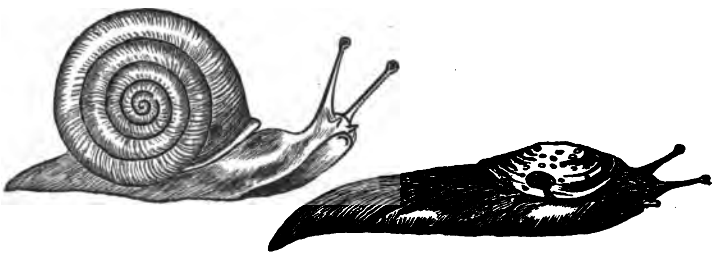


Fig. 76. Land Snails.

The next important group of mollusks contains our squids or cuttlefishes, the pearly nautilus, and the paper nautilus, as well as the strange form of the ammonites and other chambered shells that no longer exist. In these creatures, we have, among the lowest forms, the nautilus, an animal that lives in the outer room of a chambered shell; this shell constantly grows longer and wider, and the animal moves forward in it, closing off the chambered part of the tube by a partition.

Around the head are a number of soft, fleshy arms, that enable the creature to move over the bottom in a slow

and clumsy way. After a great many changes, the cephalopods, as this group is called, succeed in making a better arrangement of their parts. The shell, which serves in the lower forms for moving the body, is straightened out, made more slender, and the body wrapped around it, so that it becomes entirely enclosed in the animal. In this position, it serves as a skeleton, enabling the animal to have strong muscles to move its limbs. These limbs are constructed, with a few changes, out of the soft feelers or suckers which, in the lower forms of cephalopods, the pearly nautilus and its kindred, form two rings around the mouth, having a hundred or more of the feelers in them.

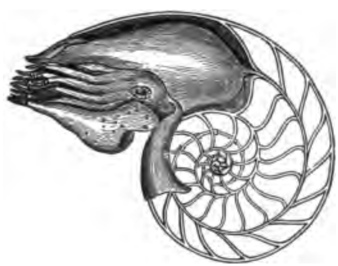


Fig. 77. Section of Pearly Nautilus.

These feelers become reduced to eight or ten in number. They grow much stouter than they were on their inner face. Suckers and hooks for grappling are developed. The mouth is provided with a strong beak. The head, the first complete head separated from the body by a neck, is formed; strong fins are attached to the sides. Unlike the lower mollusks, this group are strong, swift swimmers; though they sometimes move over the bottom by crawling, they are so successful in moving through the water that they seldom need this method of motion. These squids are, of all creatures, the quickest movers in the water,

unless they are surpassed by some of the most rapid fishes.

They move in three different ways. By closing the arms like an umbrella, they can dart backwards with great speed. In this motion they are helped by the water, which they can squirt out of the cavity where the gills lie. This water passes through what is called the syphon. Along with this water, they can throw out a quantity of inky fluid, that darkens the water like a cloud, so that the creatures can quickly slip away unseen beyond the ink-clouded water. There is an additional paddling apparatus in the strong fins that are found on the back end of

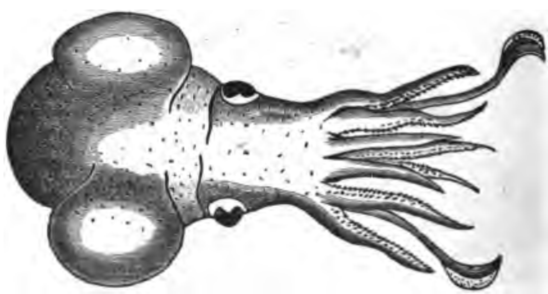


Fig. 78. Cuttle Fish.

the animal. This gives the squids the most perfect mechanism for motion in the world. They can move forward or backward with ease, and have the peculiar advantage given by the bag of sepia, that their flight is hidden. Their power of grasping is also greater than that of any other animal. They sometimes grow to a very large size. The grasping arms are as much as thirty feet long, and the body as large as a flour-barrel. They have been known to enfold a fishing-boat in their arms, and only to loose their hold when one of them was cut in two with an axe.

The nervous system of these squids is highly organized;

they have such a great amount of nervous tissue in the part we term a head, that they may be said to be the first animals to have a distinct brain. Without this perfect nervous system they could not possibly be as active and powerful as they are.

The mollusks were on earth in the very earliest time of which we have any certain record of life; and in this early day we had bivalve shells, shells like our sea-snails, and the lowest cephalopods, the orthoceratites; but these early forms were inferior to those of to-day, so that we may fairly say that the molluscan life of the earth has grown to its perfection, through the geological ages; though

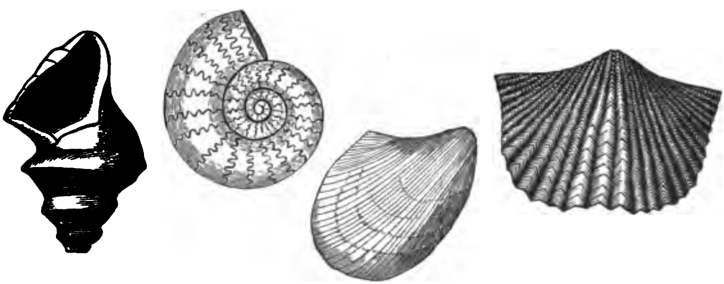


Fig. 79. Ancient Mollusks.

all its most important forms had been developed at a very early time.

Before leaving this very interesting group, we may notice some important features in which they have gained on the lower animals. They are distinctly better than the radiates, in that they have more perfect powers of motion and of sensation, and do not need the protection that is gained in communities, such as the corals generally form. Only a few low forms of mollusks are combined into communities, as are so many of the radiates. In the higher mollusks, the instruments the animal's will controls are far

more perfect than in the radiates; these mollusks generally take care of their eggs, choosing distinct places in which to deposit them, and not turning them out into the water with no care, as all the radiates do. This is the lowest form of that care of the mother for the young which is such a wonderful feature in the higher land animals.

The higher mollusks have very well organized eyes, and large, separate breathing organs; their digestive system is more effective, and through it they can digest more rapidly and perfectly, and so appropriate a larger store of force than the radiates can. Their circulatory or blood system is now strong, and capable of pushing that life and strength-giving fluid with greater speed through the body.

LESSON IV.

THE ARTICULATES.

NEXT higher than the mollusks, in their plan of structure, come the creatures known as articulates or jointed animals. These include all our worms, crabs, lobsters, spiders, and insects. In fact, every creature which has a body made up of rings, placed one after the other, as in the diagram, is an articulate.

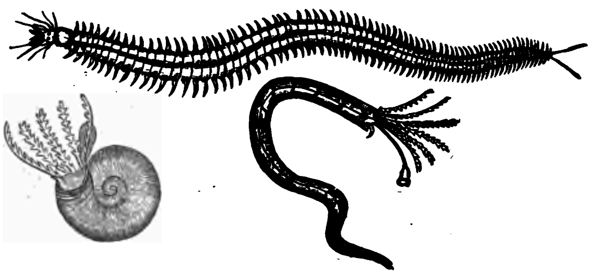


Fig. 80. Worms.

These successive rings are each very much like the other. This likeness is sometimes so great that in certain worms, if we cut them in two, the front part will heal, and the hind part form a new head, and move on without risk of death. Some worms ordinarily increase in this way. We cannot conceive this in any mollusk, for there are no such similar parts, or sets of parts, one behind the other. The only repetition of parts in mollusks is on either side of the middle line. In the articulates, at least among their lower forms, the worms, there may be hundreds of these rings, each formed on the same pattern, placed one behind the other.

When we come to the crustaceans, or such creatures as the shrimps, lobsters, cray-fish, and crabs, which are higher than the worms, these rings are fewer in number, and more different one from another. In place of the jointless, spur-like legs of the worms, we have legs like those of a crab, lobster, or insect, with distinct joints, which allow a great deal of motion. All these parts are covered with a hard, shell-like skin, called *chitine*, which protects them from assailants, and at the same time answers the purpose of a skeleton to support the muscles in their work. This outer skeleton can be moulded into a great variety of

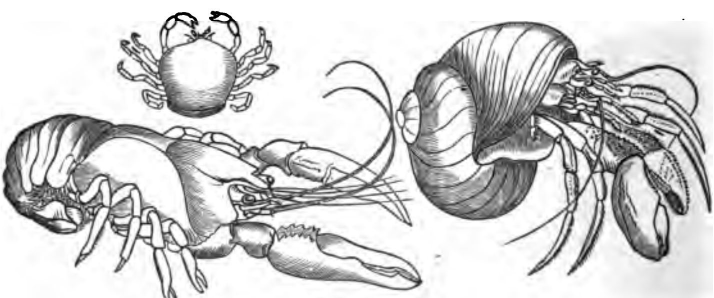


Fig. 81. Lobster and Crabs.

shapes, to suit the needs of the animal it encases. In this way, we have a greater variety of shape among the articulates than in all the other great groups of animals. This ringed covering easily fits itself to changes of habits, so that among the articulates the will of the animal finds admirable tools for its use, in a more perfect way than among any of the lower creatures.

Among the insects, we have a most wonderful variety of structure and habits. They give us such strangely varied forms as the earwigs, the spiders, grasshoppers, flies, beetles, bugs, and butterflies. Indeed, the variety is so great that there are more species or distinct kinds

among insects than among all the other animals put together. And their habits or instincts are more diversified than among other animals. We now, for the first time in the ascending scale of life, have a most careful nurture of the young by the parents,—a care that extends to the most elaborate contrivances for keeping them from danger, and providing them with food. For the first time, we find communities of insects like the ants and bees, which associate their labor for the common profit of the family or colony. They not only organize societies, but defend themselves with armies, and make warlike expeditions for the supply and profit of their communities. In many cases the young are fed on carefully-chosen food prepared with great labor. They build more carefully-arranged habitations than any other animals, their highly-developed feet and jaws serving them well in this work. Indeed, it is first among insects, as we follow up the system of life, that we have any great development of the animal mind.

The insects and articulates in general are in many ways among the most perfect of animals. This is true of what we call their minds as well as their bodies. In some strange way they do, without teaching, things that no other animal save man can be taught to do. Their only physical defect, that we can notice, is their small size. A very few of the crustaceans are fairly large creatures, but none of the insects are over an ounce in weight, and the most of them do not weigh more than a few grains. If they were as large as our quadrupeds, or even our birds, and were proportionately as strong as a wasp is, there would be no place left in the world for any other creatures. As it is, their small size, despite their means of defence, makes them feeble enemies to most large animals. Yet the greatest difficulties man finds, in his efforts to rule the earth, come from the insects.

He can easily dispose of lions or tigers, but the locusts, the white ants, and some other insects dispute the empire with him in many regions. Besides this, a host of diseases of his own body, and those of his domesticated animals, come from them.

The articulates are slowly developed in the history of the earth. They begin with the worms and certain low crustaceans called the trilobites; these two forms are found about as early as we have any distinct animals. At a later date come the crustaceans, like our lobsters and crabs; but not until just before the time of the coal period do we have the insects; at the present day, these insects are in their prime, while the worms are less important than of old, and the crustaceans have gained little in the later geological ages.

LESSON V.

VERTEBRATES.

THE lower forms of life, — the protozoa, radiates, mollusks, and articulates, — seem to have developed the most of their peculiarities of structure in the earlier stages of the earth's history; in the later times, the backboned or vertebrate animals, the kindred of man, are the only animals that show us many new plans of structures, or make great advances in the work of building a body for the uses of intelligence.

The highest of the great groups of animals is the type of vertebrates or backboned animals. In this group we have a plan of structure which is very different from that of the lower plans of radiates, mollusks, or articulates. It includes the fishes, reptiles, birds, and mammals.

Fig. 82. Amphibian.

The principal forms of vertebrate animals are tolerably familiar to all, so we may give an even briefer account of them than of the lower animals.

Lowest in the scale of vertebrate life come the fishes. In them we find the vertebrate body shaped only for swimming: the parts which are feet, or wings, or hands, in their land kindred are, when present, always in the form of fins. There is no distinct neck. The animal generally breathes by means of gills placed in the back part of the head, in the mouth cavity, which take the air from the

water. They almost always lay eggs, but a few have their young born alive. Their blood is cold.

Above the fishes in structure, and closely related to them, we find the group of vertebrates known as amphibians, a name given to them because they *generally* live for

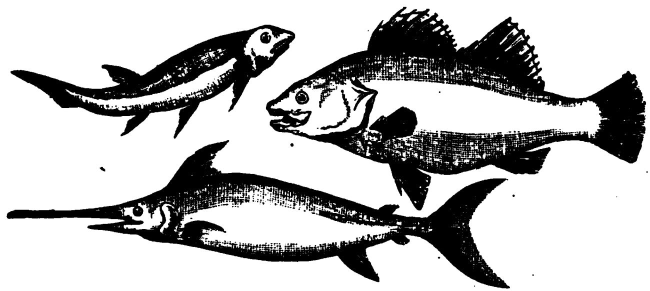


Fig. 83. Fishes.

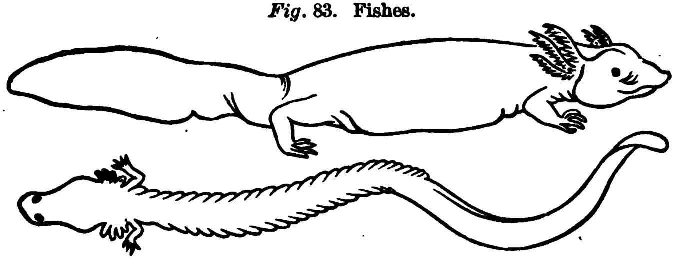


Fig. 84. Salamanders.

a part or the whole of their lives in the water, in the form of tadpoles such as those of our common frog. In this group come the water-dogs, the salamanders, and all our frogs and toads, as well as many strange-shaped ancient forms that have disappeared from the earth. These creatures are fish-like for some time after they leave the egg, swimming with the long tail-fin, and breathing with gills. Some of them never leave this condition, but others, as our frogs, toads, and salamanders, pass through a wonderful change,—their tails shrink, their legs sprout out in their

proper places, and their gills drop away, so that they afterwards breathe the air, and can live on the land.

Next higher than the amphibians come the reptiles, which include our lizards, crocodiles, alligators, turtles, and snakes, as well as a host of great creatures belonging in the ancient times of the earth, but long since extinct. In these creatures there is no fish-like tadpole state; they all breathe by means of lungs from the time they leave the egg.

Fig. 85. Lizard and Flying Reptile.

These are the first very successful land animals: among them we find flying, swimming, and walking forms; so, for the first time, those forms of progression which gave the vertebrates their great place in the world were brought into use. During the middle ages of the earth's history, and until the suck-giving creatures came, these reptiles were the monarchs of the world.

While the reptiles were in their prime, the birds, the next higher group of animals, appeared. At first they were a good deal like feathered flying lizards. Their tails were long, like lizards, and theii jaws had sharp, lizard-like teeth. The great difference between them and reptiles is in the possession of a covering of feathers, and their very warm blood. It is the warm coating of feathers

that protects their bodies from the cold, and makes a warm blood possible. This warm-blooded condition is brought about by a stronger and more perfect circulation, so ar-

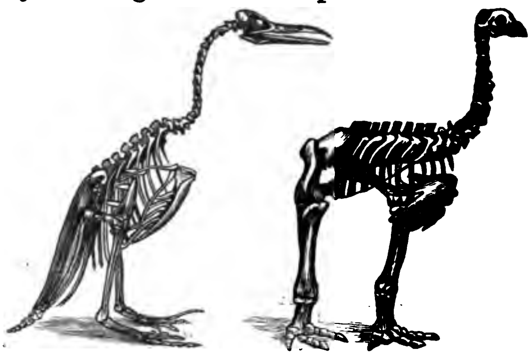


Fig. 86. Hesperornis and Dinornis.— Fossil Birds.

ranged that each time the blood makes the circuit of the body it is passed through the lungs, where, being exposed to the air, a part of its carbon is combined with oxygen, or burned, which gives out a supply of heat to be distributed

Fig. 87. Apteryx and Dodo.

through the body. This supply of heat is greater in birds than in any other animals; and, as the activity of the body depends on the temperature of the blood, they are very strong for their weight.

Highest of all animals come the mammals. All these

creatures have their young born alive, and the mother gives them milk.

There are two principal divisions of this great class of mammals. The lower and earlier to live on earth is that to which the kangaroos, opossums, and their kindred belong. In these the young are born in a very imperfect state, and are sheltered in a pocket of the skin which covers the teats of the mothers. In this pouch they remain for some weeks, until they are strong enough to move about, and for some time longer they return to it for the mother's milk and for shelter.

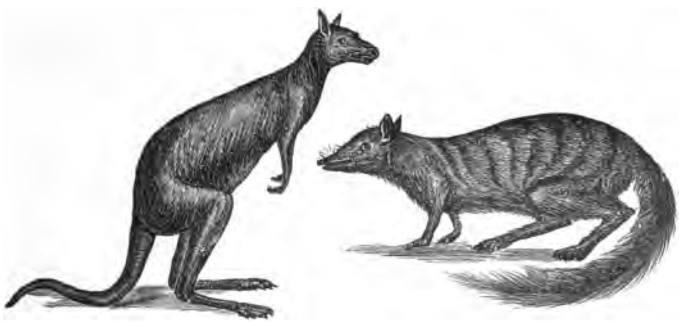


Fig. 88. **Marsupials — Kangaroo and Myrmecobius.**

The other great division of the mammals is without this pouch, the young being born in a too perfect condition to need its help. This group includes all our ordinary four-footed beasts and man himself. In the mammals, hair was developed to serve the purpose of keeping in the warmth furnished by the warm blood, which they have in common with the birds. This hair, and the milk-giving by the female, are features that separate the mammals very sharply from all other animals.

In the vertebrates, we first find an internal jointed skeleton which provides two chambers for the reception of

the soft parts of the body; one enclosed by the ribs for the organs that support the mere animal life of the body, such as the stomach, the heart, and lungs, etc. The other, smaller and more completely enclosed, is formed by the bones of the head and the backbone, and encloses the most important parts of the nervous system,—the brain and the spinal cord. These backbone parts of the skeleton are so jointed together as to be at the same time rigid and elastic, and give a better protection to the inner parts while allowing a greater freedom of movement than any other arrangement could do. To this central skeleton there are attached never more than four limbs. These, like the trunk, have an internal skeleton that supports them, and enables their muscles to work them.

Fig. 89. Irish Elk.

In the importance of the nervous system, and in the arrangement of the limbs, this group of vertebrates stands apart from all other animals. In no lower group is the nervous system so large or so cared for; in none are the limbs so determined in their forms, or so fitted for varied work. We see how suited they are for their work, when we consider that by simple yet effective changes they form the fin of a fish, the foot of the horse or the lion, the wing

of a bat, or the hand of man; — all these varied parts have come by slow changes from one ancient form of limb.

The nervous system permits the work of a higher intelligence than we find in the lower animals. In place of habit or instinct, a blind, unreasoning working of impulse, we have, as we go up on the vertebrates, a constant increase in the likeness of the mind's working to our own. We see among the fishes a certain care for their young. This carefulness of the offspring grows more and more marked, until, in the higher forms, such as the birds and animals that give suck, it takes the form of parental love.

Not only through the mind, but through the body, these vertebrates give more help to their young than any other group of animals. Among those forms that lay eggs, — the fishes, the reptiles, and the birds, — we find a contrivance for helping the young that reminds us of what occurs in the plant world. Among the higher plants the young is helped by a store of concentrated food that makes the mass of the seed. While in the lowest forms there is no such helpful store. Thus, in the lower animals, the parent gives the young life without placing in the eggs any store of food to sustain it in the earliest work of existence. In the fishes we find that there is some provision in the egg for the sustenance of the young while it is making the first stages of its growth, though the amount is but small, for the fishes commonly lay many thousands of eggs at a time, so that not much can be done for any one. In the reptiles we find the eggs greatly diminished in number; and in each a larger store of food is placed, forming a distinct yolk. In the birds the eggs attain their perfection; they are still fewer than in the reptile, and are often as much as one tenth the weight of the parent, so large is the store of nutrition that is placed in them for the help of the young in its growth. Besides this, the mother by the nest, the warmth of her

body, and the food she brings them, does much for her young. In the highest group of vertebrates, the mammals, when the young are born alive, the mother's milk provides a yet better method of helping the young in their growth. In these, the highest groups of vertebrates, the birds and mammals, the blood is warm as it is in none of the lower forms. This guards them against changes of temperature, and makes them better fitted to endure the struggle of life in cold regions. Thus, with each step of advance, there is more help given by each generation to that which is coming on to take its place. While we can trace the improvement of animals, as we rise higher in the scale of being, in a great many ways, there is no other way in which it is so beautifully shown as in these contrivances of mind and body for helping the weakness of the young.

The vertebrates do not seem to have lived in the earliest stages of the earth's life-history. They first appear some time after the other groups of animals become known to us. First, come the fishes; then, at a much later date, in the coal-bearing rocks, we have creatures related to our water-dogs and salamanders; then, just after coal, we have the kindred of our alligators, which for a long time filled the lands and seas with many strange forms of reptiles; then, in the Jurassic time, as it is called, that is, some distance above the coal, we have the first mammals. These were little creatures related to our opossum, and called pouched mammals, because they carry their young in a pouch on the belly for some time after they are born. These first suck-giving animals were insect-eaters, as are many of their kindred at the present day. It is a long time before the mammals begin to have the first place among animals; for many geological ages the reptiles still held the control of the lands, the seas, and the air with their giant forms. Finally, however, these reptiles began to fade away, and

the mammals to grow larger, more varied, and more powerful. The higher forms gave up the use of the pouch, which has been kept only on a few species of opossums that live in North and South America, and a hundred or so kinds that are found in Australia. These pouched species are fading away from the earth, and are being replaced by the non-pouched forms.

There are very many other features in which the vertebrates show their advance beyond the conditions of life in the earlier types of animals; of these we may only mention, here and there, a striking case.

All the radiates and mollusks are entirely voiceless; so, too, are all the crustaceans; only some of the insects having the power of calling to others of their kind; and in all cases this is done by rubbing hard parts together, and never by anything like the voice, as we understand it. But nearly all the vertebrates above the fishes have some form of call made by driving the air out of the lungs in such a way that it vibrates membranes stretched across its path. This voice is found in its beginning in the fishes, some of which force air out of their air-bladders, which are imperfect lungs, and thereby make a call that their mates can hear. The frogs and toads have distinct voices; so have many of the higher reptiles. The birds all have some voice, and all the mammals have it. This means of communication between one animal and another is a sign of growing sympathy between kindred creatures. Except among the insects, there is hardly a trace of this feeling in the animals below the vertebrates; it is peculiarly the mark of the mammals; they feel for and help each other.

Thus, we see that the advance in the mind of animals seems to go with the bettering of their bodies. The great aim of all animals seems to be to get better and better means for the ever-growing intelligence to use in its work.

Last of all, among the great results of this world, comes man himself. In his structure we see many relations to the other mammals, and there can be no doubt that his body has been in some way made from the forms of the mam mals below him in structure, so that man, as an animal, stands in close relation to the lower life of the world; but when we come to consider the mind of man, we find something very widely different from the mind of the lower animals. In the lower animals we find a trace of all the faculties we find in man, but they, unlike man, are not capable of indefinite advance. They are bound down to a certain narrow round of thought and action; but in man we have a creature able to go forward without limit; so that we may say there is no such relation between his mind and the minds of lower creatures, as there is between his body and those of animals. Mentally, he belongs to another system of creation from the beasts.

When we study the forms of the lower animals, we do not find one series of steps leading up from the lower to the higher forms, but different groups, each with its own peculiar plan of structure. There have been many experiments in the building of habitations for intelligence. The most of these have gained only a partial success, for the reason that the plan of the structure did not allow the necessary perfection of the body. Of all these efforts, that of the vertebrates was the most promising, for it gave by its skeleton, by its careful building of the nervous system, by its plan of limbs, the best chance to go on to a high structure. Out cf the many trials, the great success of man was at length reached.

The naturalist cannot believe that man was a mere accident; he is rather the being to which the world in all its efforts was constantly tending.

CHAPTER X.

THE NATURE AND TEACHING OF FOSSILS.

LESSON I.

HOW FOSSILS ARE FORMED.

IN the later pages of this book we shall often have to speak of fossils, or the remains of animals and plants that are preserved in rocks, so that it is well to get an idea of what they are, and how they are formed.

A few living things, such as the jelly fishes, the slugs or shelless snails, etc., have soft bodies which at death dissolve and leave no solid parts behind. But most animals and plants at death leave in the water or upon the earth bodies that have a certain solidity; woody matter in the case of plants, bones in the case of higher backboned animals, hard skins as in the insects, crabs, lobsters, etc., or shelly matter as in the shells and corals. If these hard parts are left uncovered on the surface of the soil or on the bottom of the sea for a long time, they utterly decay and fall to dust. Examine any old forest; it has grown for, it may be, hundreds of thousands of years; if it were not for the rapid decay of the leaves and branches that fall on the earth, the waste-heap would be many times deeper than the tallest trees are high; but there are only a few inches, or, at most, a foot or two of vegetable mould on the ground where it stands. If all the bones of all the birds and beasts that have died in this wood had remained

there, the soil would have its surface covered with these remains; yet we may search for days and not find a single bone in a square mile of forest. All such remains rot away speedily; the skeleton of an ox left on the surface of the ground is decayed in a score of years and falls to powder. So we can say that nearly all the bodies of animals and plants that die on the land fall speedily to dust. Yet there are certain ways in which their remains may in rare cases be preserved. If the trunk of a tree falls into a wet swamp or a pond, and sinks to the bottom, it will only partly decay, turning black, but retaining its shape for many thousand years. Thus, in New Jersey and elsewhere, they dig out these buried trunks and use them for timber. Sometimes, as in Ireland, they are found even after the forests in which they grew have entirely disappeared from the region. In such swamps we often find the bones of animals which have been drowned there; as, for instance, in the swamps of Ireland are found the bones of the great elk, the largest horned creature of the deer tribe that we know. Then, too, we may find the remains of fishes and water shells. If it happens that such a swampy bed is buried under the sea, and covered with other strata, it may preserve to us the remains of a very ancient time; such, in fact, are the coal-beds that are now giving the wealth to the greatest nations of the world. It may sometimes occur that forests and swamps, with the dead and living things they contain, are buried under a shower of volcanic ashes, or the dusty matter thrown out by volcanoes, and so preserved from decay. Or, it may happen that in limestone countries, the remains of animals are swept into caverns, and buried under the floors of stalactite, and so sealed up from the air; or, in yet other cases, the remains may be buried in the beds of mud and sand along the banks of rivers.

But all these methods of burial on the land are not able to save much of the forms of land life from utter decay. This we may see by noticing how very seldom it is that we find any remains of the creatures that lived in this country before it was settled by the whites. I doubt if my readers have ever found the bones of a deer, a bear, or a panther anywhere in the fields or in the openings made for roads or cellars, though scores of these animals have died on every acre of the land. There is no provision for their burial, and so they almost always decay.

So it is on the land, but in the sea it is quite otherwise: there every animal that leaves at death a solid frame gives its remains to the bottom, unless it goes into the jaws of some enemy, as, in truth, it oftenest does. Once on the sea-floor, it finds a host of animals glad to use anything in the way of food that the body may afford. Yet it happens that very many of the dead that come to the sea-floor are buried in the mud or sand that is constantly gathering there, and in this way are secured from decay. We need only drag a dredge over the sea-floor, at almost any point from near the shore to a depth of twenty thousand feet, to gather a lot of this bottom mud, in which we find shells and other hard parts of animals that have been already buried in the muddy deposit. We can easily see that in time they would be sealed under a great thickness of this ever-gathering waste that covers the sea-floor in a sheet as wide as the oceans.

We have now seen most of the ways in which the dead bodies of animals and plants may be buried in the earth's crust; we will next try to show how they are preserved from further decay. It usually happens that when the bodies of animals or plants are buried in the rocks, certain changes occur in them. If the remains are laid at a little

depth beneath the surface, as in human graves, the rain water and air penetrate to them, and they fall into complete decay, becoming mere dust that is seized on by the roots of plants, and lifted once again into life. But when these remains are buried where neither the rain-water nor the air can get to them, they may preserve their structure for a very long time; for, when these change-producing agents are kept away, the principal forces that bring decay are not free to act upon the remains. They are then in much the same condition as the preserved vegetables and meats that are enclosed in well-sealed cans, and there is no reason why they should ever decay, for the air, that by its oxygen rots them, is shut out. So it comes about that a mammoth buried in the ice of Siberia can have even its eyeballs preserved for some such time as one hundred thousand years; or that a grass-like plant buried in the far more ancient coal-beds should keep so perfectly that it remains flexible to the present day; or the shells of the yet remoter Silurian age should keep a little of the color which they had in their time of life.

But it generally happens that the bodies of these buried creatures undergo certain changes that gradually destroy their original shape. They are often somewhat heated, owing to their deep burial beneath the rocks that are laid down on them, and their consequent holding in of the heat that comes up from the depths of the earth. When this occurs, the hot water that lies around them often takes away the lime of their bodies, and deposits flinty matter, or makes other changes. Thus, it has happened in a mine in Utah, that around the leaves and stems of fossil plants silver has been found deposited. If the heat is greater, it often occurs that the whole of the fossil disappears, leaving only a stain on the rock, or even no trace of its having

been there. When rocks like limestones become crystalline, all the fossils commonly disappear, though they may have been there in great plenty and excellent preservation.

Thus, it comes about that while the creatures that live on the land are rarely preserved to us, those of the sea are often buried in the rocks; and when the rocks in which they are buried are lifted above the sea, and worn by the frost or rain, the fossils appear in great numbers, sometimes so thick as to cover the hillsides with the well-preserved relics of a life that passed away from the earth many million years ago.

It is from these remains that the geologist is able to make up the history of life, and to construct a picture that represents the animals and plants that lived from time to time in the past. In this work long practice has given great skill; so that, from a few bones, or a fragment of a shell, it is possible for a naturalist to form a tolerably clear idea of the creature to which these fragments belonged, and something of its habits of living. Thus, the structure of the teeth will show us whether an animal was flesh or grass eating, as is seen in the case of the dog and sheep, where their teeth are precisely fitted for their different sorts of food. Often, a single tooth of any kind of an animal that has left us no other part, or fragment of an insect's wing that is all which has come down to us, will serve to prove to trained eyes and minds the existence of creatures of a certain mould at a particular time in the past. So, out of the shreds of the life that lived in ancient days, taking here and there the fragments as they happen to come to us, we can gradually build a tolerable museum that will show us how this life stood at each time in this past. We know in this way, with perfect certainty, that over a vast duration of time the life of the earth's

surface has been slowly changing. Now and again particular kinds of animals and plants disappear, and their places are taken by others. In this way the whole of the animals and plants of our globe has been many times changed, the old kinds giving place to newer and higher forms.

CHAPTER XI.

THE ORIGIN OF ORGANIC LIFE.

LESSON I.

HOW NEW SPECIES ARE MADE.

AMONG the questions which the student of the earth finds always before him, in the study of its history, are how animals and plants have come to be; how this life began; how, from time to time, these living creatures have disappeared, and been replaced by other kinds. These are all hard questions, and we cannot yet give them full answers. Until modern times, students did not know that there had been a very long history to life, in which all the kinds of beings had often been changed, giving place to other kinds; therefore, until our own day, the general opinion was that all the kinds of animals and plants now on the earth had been created from the dust in the shape we find them. But, when in this century it was found that before the coming of each of these living animals and plants there were other forms closely resembling them, yet of different species, and that this chain of beings stretched clear back into the past, the animals becoming more simple as we went towards the time when life began, it was gradually learned that these animals had in some way sprung from each other. For we cannot well believe that the Creator would make such relationships between creatures, creating each like that which went before, yet with a difference.

It is far more reasonable to believe that the living forms have sprung from the kindred forms that have passed away. So strong is this argument, that there is probably not a single person living who has been a careful student of animals or plants who doubts that the life now on earth has sprung from species or kinds that have passed away. The only doubt is as to the means by which the change from one to the other has been brought about. This is the question to which students of nature are now giving the most of their attention.

So far but one clear way has been found in which the change can be accounted for, and while it cannot explain more than a part of the puzzle, it is an important help to our knowledge of life. This partial explanation is known as the Darwinian theory, taking its name from the student who first suggested it. This explanation rests on the fact that each animal and plant in the world has many more offspring than can find a place in the world. Some fish, for example, lay as many as a hundred thousand eggs each year, while, on the average, only one or two of these young live to grow up, the others of the brood falling a prey to enemies of one sort and another. The result is the same with every animal and plant: they have more young than the world can give a place to, for all the seas and lands have about as many animals and plants as they can give a chance to live; so it comes about that the world of life below man is one great conflict, an unceasing battle for life, where each creature struggles with its neighbor who wants the same food or place. Nearly every living thing has two sorts of enemies in the world: passive enemies, who occupy the place in sea, on land, or in the air which the new-comer needs; and active enemies in the creatures that prey upon it, and try to make food

of its body. We see that these creatures are constantly trying new plans to make themselves better fitted to win success out of their difficulties: they become swifter of foot or wing; they get stronger defensive weapons; they invent new habits that will elude their enemies; in a thousand different ways they change to meet their needs. It is certain that to these chances, which serve to help the creatures in the long battle for life, we owe a great part of the changes that are constantly arising in the forms of living things. The only trouble arises when we try to see just how the change is brought about. We may, in part, explain it in this way: among all the young of any animal or plant, each differs somewhat from any other. These differences are generally slight, but they may be enough to give the particular creature a better chance to live; it may be stronger limbs for flight or chase, or some difference in habits, or any other profitable quality of its body or mind. In other words, those that vary in the direction of profit will be more likely to survive in the struggle for existence than those that vary in other directions. Next, we must notice the fact that each living creature is likely to give its peculiar traits of body and mind to its descendants, so that they will have a share of the same peculiarities that the parent had, and on these creatures, the same principle of survival of those that are fittest for success will again act, making the profitable feature stronger than it was before. If longer legs or stronger wings saved the parent, it is likely to give those longer legs or stronger limbs to its offspring, which will give them an advantage over the children of those other members of the same species that have not this peculiarity. Some of these descendants of the long-legged or strong-winged animal will probably

have these parts better developed than the parent, and so its children will get the advantage of its cousins, and thus prevail over them. From generation to generation, the wings become stronger, or the legs larger, until a race is made that differs very far from the creatures from which it originally came: that we call it a different species. In time, all the individuals of the species who have not changed in this way will be destroyed by their enemies, so that the old species will disappear, and the new take its place.

Although this is a very probable explanation, and may account for many changes that take place among animals, it cannot be said that it is proven, nor can we expect to have a chance to prove it for a long time to come. The life of any one student is but a day compared with the slow-going changes of the world, and we know too little of the struggles of our lower kindred with their enemies to be able to see just how the fight goes with them. The only place where we can see anything like this process of choosing the fit for life, and the unfit for death, is in our household and barnyard animals, and the plants of our tilled grounds, — these creatures which man has seized on and forced to help him in his particular battle. These domesticated plants are taken out of the combat of the world; man does not allow the wolves to seize his slow-footed sheep, nor the swift-growing weeds to overcome the plants of his gardens or his fields, but in place of the selection of nature, he uses a selection of his own for his own purposes. When, for instance, he finds among the constant variations of his sheep, an animal with more wool, or with shorter legs, that make it unable to jump fences, he breeds from this animal, and sends the others to the butcher. He seeks among the young of his chosen sheep the lambs that have the best wool, or the

shortest legs, and sells the others; and so in certain places he has lengthened the wool and shortened the legs of these animals until they are so unlike their ancestors of fifty years ago, that if we found the two races wild, we should call them different species.

What, in one case, man does for profit, he does in another to please his fancy. Dogs and pigeons, for instance, he breeds for the amusement of having different kinds; and so our dogs have come to be of many distinct forms, and between the little sky-terrier, the burly mastiff, and the long-legged, agile greyhound, there is a greater difference of form than between foxes and wolves, or sparrows and robins, — things which we regard as very different species among wild animals.

The way in which animals change in the hands of man must be regarded as good evidence that they may be modified in the hands of nature where the penalty of death is administered on all who do not conform to the rules of life; to all who do not strive to go onward in the race.

Although we cannot regard this theory of changes among animals and plants as perfectly proven, there can be little doubt that it accounts for many of the changes that take place. It is also likely that there is a host of changes, perhaps the greater part of them, with which these selective processes have little to do. It is not likely that anything so wonderfully complicated as the world of life can be due to one cause. We also easily see that this idea, at most, accounts for only a small part of the wonders of animated nature. The real marvel is, not that animals and plants vary, or that their changes lead to the making of new species, but that these changes have not been by haphazard, but in a way that has led from the lowest creatures to man. It is the fact that these changes

lead to such an end that is the really wonderful thing. We cannot believe that if they occurred at haphazard, any such a world as we have could have been made.

It must not be thought that all the changes that take place in the world of plants and animals lead to a higher and more perfect life. If the animal adopts modes of life that require a more perfect body or a more active mind, we find that it goes upwards in its changes; if, on the other hand, it takes up with baser ways than its ancestors, it may become more and more degraded in its body and mind. The snakes, for instance, were once four-limbed

Fig. 90. **Snake, Cheirotes and Bipes.**

animals that moved like the lizards, but through change of habits they came to other and lower needs, so that their limbs were no longer useful, and shrunk away. A few of the serpents have a small pair of forelegs which are so small that they serve scarce any other use, save to show how they have been degraded from higher forms. The sperm whales come from creatures nearly like our bears, that were pretty well up in the world; but their ancestors took first to living partly in the water and partly on the land; then, finally, to an altogether water-life, so they have lost their hair, their hind limbs have shrunk away, their fore limbs become reduced to paddles, and the whole body

has taken on the outside form of a fish; so, since the beginning of the tertiary time, the whales have been degraded from a high to a low place among mammals. There are many other cases among animals where the body, in part or in whole, has been lowered from a higher plane of structure to a lower by the change of habits. Some of the most instructive of these examples we find among cavern animals. In them, the eyes sometimes entirely disappear, the creatures having taken on a habit of living where the light can be of no use to them.

It is a fact that the higher the level of any animal's life, the more the chance, that through some change of habit the creature may lose the gains its ancestors made for him, and fall, far more swiftly than it rose, to a lower level of existence. This is doubtless true of man, as well as of his lower kindred, and especially true of his moral and mental nature. Any degradation of habits lowers the individual, and the degradation will be handed on to his children. If we realize this truth, it gives us a keener sense of our duty to our whole nature, — to our bodies and our souls; our very life depends upon a wonderful guidance that has led us slowly up the long ladder of life that stretches from things inanimate to man. We stand upon a mountain-top nearer to Heaven than all else, with the privileges that are denied to other beings; yet the very height bids us to tread carefully, lest we fall into the depths below.

With the coming of man, the progress of life on this earth seems to have been, in the main, completed. Some changes may take place in the lower life; the insects and other lower groups may become more varied, and rise to a higher level, but man is the highest of all the backboned animals. The earlier days of the earth seem to have been times for the growth of bodies, while our own time is

peculiarly an age of mind. The future of this wonderful world comes each day more and more into the keeping of man. He subjugates its animals and plants to his uses; destroys them, or changes their form and habits to his needs; already he has destroyed several species of birds and other animals, and, though some insects now baffle him, he will doubtless, in the coming ages, have the whole world at his feet. But, when he comes to a sense of the duties which his power lays upon him, he will surely be merciful to this poor dumb life that has fought with his ancestors in the great battle of the world, through all its ages, and has failed to win the crown of life that is his alone.

LESSON II.

PROOF THAT THE EARTH IS VERY OLD.

It is only slowly, and with much difficulty, that we have learned how ancient a thing our earth really is. Many figurative accounts of its sudden creation have been found in the sacred books of various Eastern peoples, but these accounts cannot be taken as representing the primal facts of the earth's history. Man is, himself, so short lived, that he cannot imagine the vast duration of the Past since life began upon the earth; at most he may remember a century of time, yet this term of the longest human life falls like a drop into the great sea of geological time.

Let us notice some of the simpler proofs of the earth's great antiquity. Take any pebble in hand: consider what time it requires to shape this bit of stone to roundness; how it must pound on the seashore, roll in a river-bed, or grind beneath a glacier before it becomes slowly beaten into this shape; yet there are great masses of rocks, thousands of feet in thickness, and stretching for hundreds of miles, made up of such pebbles. Look at the sands of our shores, or of the tens of thousands of feet of sandstones that cover the earth, and consider how long it must have required to bruise their grains into this small size, and bear them into the sea where they were built into rocks. Then, after they were built on the sea-floors, they have been lifted into the air, and afterwards carved into valleys and hills.

Take a thick section of limestones, say one thousand feet in depth, such as we may find in many countries;

consider that all of it has been in the bodies of animals that have grown and died in the sea, slowly giving their dead bodies to make the limey beds, it has thickened, not faster, perhaps, than the hundredth of an inch a year, until at the end of one million two hundred thousand years it would be finished. There are deep valleys carved in this limestone, such as we may find in many regions where streams cut through hills or mountains. Now, in old countries, such as those of Europe, we can often prove how deep the valley has cut in one thousand years, or in the natural term of life of about twenty generations of men; we find, perhaps, that the valley deepens at the rate of two feet in one hundred years; but as the valley is, say, three thousand feet deep, we see that it has required, at least, two and a half million years for it to be carved out. In fact, there would be a yet larger time required, for the reason that the hills that form this valley are slowly wearing down, as well as the bottom of the valley itself, so that if we go back to the time when water began to run down these slopes and carve them into hills and dales, we might have to go many times as far into the Past.

Take the Falls of Niagara: these falls have slowly retreated up stream all the way from Lewistown, near Lake Ontario, to their present place; they are still mounting up stream, as their edge wears away, at the rate of about four feet in one hundred years, so that seventy thousand years has certainly elapsed since they began to form.

In the peninsula of Florida, the southern part of it, at least, has been formed by successive coral reefs, which grow, one after the other, further and further southwards. Agassiz has reckoned that it required hundreds of thousands of years for these reefs to grow; yet both these great works, the building of the Florida reefs and the retreat of

Niagara Falls up to its present point, are among the most recent things in the shaping of the world,—almost every river-valley and every hill in America is an older monument of the earth's forces. We know that the lands change their level very slowly along most shores; the change is so slow that we call the land stationary; the greatest change is that which is going on in Sweden, where the land rises as much as three feet in a hundred years; yet we know that many lands have been alternately sunk below the seas, and lifted into the air, perhaps a score of times. To bring about such changes requires an inconceivably long time.

If we study the life history of the earth, we find other things to show us how long the Past has been. Plants and animals change but slowly; we know that there has been very little change in the last four thousand years, for in the Egyptian catacombs we find a host of mummied animals and plants, every one the same as the living kinds. The life on the earth changes very slowly, one kind dying and another coming in, so that it requires a vast period altogether to change the life; yet we know that many times, perhaps fifty times, a nearly complete change of life has come about, so that any creature living through all the ages that living beings have been on earth would have been able to see about all the life renewed by these slow changes, at least fifty successive times in the earth's history.

There are many other evidences that the duration of the earth's past is far greater than we can imagine, or in any way figure to ourselves. Putting together all the facts that we have, it seems tolerably certain that since the time when the earth was first fit for life, somewhere between one hundred million and four hundred million years have

gone by. We may build a sort of picture of this great length of time in this way: in one mile there are about five thousand feet; call the whole time of the longest human life one hundred years; measure off one long step on this mile of length to represent one such human life, then the whole mile will represent only one-half a million years, and it would require, perhaps, a thousand miles of length to give us a diagram which should represent the time since life came on the earth; and three feet on this length would represent the years of the longest-lived men. When we have seen what happens in the space of one human life,—thousands of earthquakes and volcanic eruptions; thousands of great storms that beat the shores; vast stretches of land grown dry or sunk beneath the sea; pestilences and famines, and a myriad other changes, and then multiply these by a thousand times a thousand, we gain some faint idea of what a epoch the world's past has been, and can imperfectly imagine how great the changes have been in such a time.

A large part of the work of the geologist consists in an effort to trace out the history of this past, to find how the lands and seas were shaped in the different periods of the earth's history, what creatures were living at the several times, and how they were succeeded by other and higher forms. This has been slow and perplexing work, but there have been several thousand persons at work upon it during the past hundred years or more, so that we now have a tolerably clear account of the stages through which the earth has passed in its long history. In the following chapter a brief outline of this wonderful history is given.

It is not easy to give in a few words an idea of how the geologists have succeeded in patching out this record of

the earth's long history, yet it is important that the reader should get some idea of the ways in which it has been done.

One of the most useful clews that we have to the history of the earth is had from the beds of rock which we may find on the land. We can show how these beds teach by noticing what is shown in the figure. This represents in a rough way a section from the Blue Ridge of Virginia, westward to beyond Cincinnati, Ohio. On the right, the crumpled rocks are composed of granites and other crystalline rocks; to the left, the beds show limestones, sandstones,

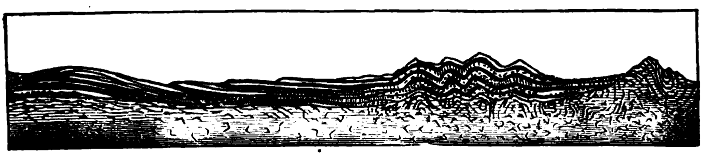


Fig. 91.

Section from Blue Ridge to west of Cincinnati, Ohio.

and slates; those covered with dots, conglomerates; those shaded black, the beds that bear the coal. Now, as all these beds, except the coal, were formed beneath the sea, we perceive how great must have been the changes since the earliest of them were formed. These changes were as follows: first, the mountains of the Blue Ridge existed as mountains rising above the sea before all the others were formed; this is shown by the fact that the lowest beds contain pebbles worn from their rocks, and they lie up against the granites, etc., in what is called an *unconformable* position; that is, the newer beds do not slope the same way as the old, showing that the old had been tilted

and covered before the new were formed; we see that these beds including the coal measures are tilted up to form the Alleghenies.

Going further west, we see a broad ridge in the rocks. At Cincinnati there is a very wide, low mountain. By closely examining the position and character of the rocks here, we can prove that this ridge was in part formed long before the time of the coal. It has on its western side fossil coral reefs, such as are now formed on mountains in the warm seas where a current sets against their shores. Next, we notice that the various rocks that are represented in this diagram are thickest towards the east, and thin out towards the west; the beds of pebbles abound near the Blue Ridge, and fade out westwardly into sandstones or fine muds. This shows us that the land was to the east of the old sea-floors on which these deposits were laid down, for pebbles always grow smaller as we go away from the shores.

There are many other ways in which geologists are able to infer the succession of events, and the conditions that existed on the earth's surface in past times. There are, indeed, many other well-founded conclusions that can be drawn from this section; but enough has been noted to indicate one of the principal ways in which geologists work. The rocks form a great stone book, the pages are often ragged, and the signs hard to decipher, but the story is still plain if we study it well.

CHAPTER XII.

A BRIEF ACCOUNT OF THE SUCCESSION OF EVENTS ON THE EARTH'S SURFACE.

LESSON I.

THE EARTH BEFORE ORGANIC LIFE BEGAN.

THE earliest stages of the earth's history are not written in its rocks, so that all we know about the matter comes from the studies of astronomers upon the distant worlds of space, many of which are passing through the changes that our world must have endured in becoming fit for life. These very distant stages of change were probably about as described below.

Fig. 92. Nebulæ of Orion.

In the beginning our earth, along with the sun and the other planets of the solar system, existed as a very large mass of finely-divided matter much like a gas. Seen from

the distant stars through a strong telescope, it would have appeared as a faintly shining mass, like what astronomers call *nebula.* The particles of this gas all attracted each other, which caused them to fall in towards the centre of the mass, and as they fell they all began to swing around in the same direction as the planets now swing around the sun. Then this mass of matter began to divide into circles like those strange rings that girdle the planet Saturn. When these rings became tolerably separated from the mass within them, they broke up, and were gathered into a sphere. As the old outer rings of Saturn

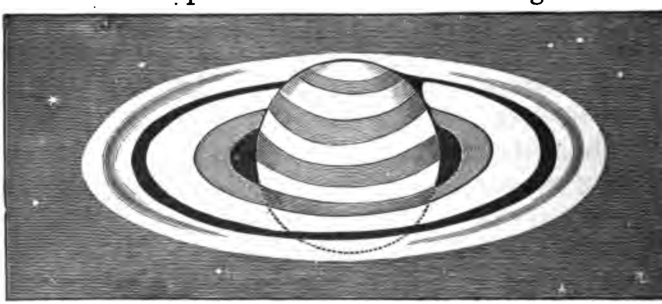


Fig. 93. Rings of Saturn.

have been changed into moons, one after another of these rings formed in the great mass of gas, and were gathered into the separate planets. These several planets each then shrank, forming separate small rings, like the great rings from which they were shaped; these rings breaking to pieces produced the moons or satellites of which all the planets, except possibly Venus and Mercury, have one or more. As if to prove that this was the way in which planets and moons were formed, the planet Saturn preserves one of its rings that has not collapsed into a moon, but remains as a ring, as is shown in the diagram. Although not perfectly certain, it is almost so, that this

is something like the first stage in the development of our earth.

When it first separated from the great shrinking mass of our solar system and became a sphere-like body, the matter of our world was very likely still a mass of gas, which was more than half a million miles in diameter, extending beyond the orbit of the moon. It then could not have been as solid as the air that now lies on its surface. But, as it shrank into more and more solid forms, it too formed an outer ring, which in time was broken up and gathered into our moon.

As the remaining mass of our earth became more solid from the falling of its particles towards the centre, a great deal of heat was developed. We see when a meteor falls on the earth, or a hammer falls upon iron, that heat is made to appear when the motion is arrested, and as these particles of matter tumbled towards the centre of the earth's mass, the whole gradually became hotter and hotter, until the gas was by the crowding together of its particles converted into a very hot fluid sphere, not much larger than the present earth. As the vacant space outside of the earth was exceedingly cold, having a temperature of one or two hundred degrees below zero, this great boiling mass of earth-matter slowly parted with its heat, until it became solid enough to bear a crust of frozen rocks that enclosed the hotter matter within. Then the water which had been kept in the state of gas above the earth came down upon its surface and wrapped it with the oceans. Now, for the first time, the earth began to be like the world we know; the machinery of its physical life, the winds, the ocean-currents, and the rivers, came into being, and all was made ready for life to begin. In what way life began we do not know; we only know

that all our experiments appear to show that life, even in the lowest forms, seems to be always derived from other life, and not able to start even in the simplest forms from dead matter. But once begun, the whole world of progress became open to it.

LESSON II.

HISTORY OF ORGANIC LIFE.

THE geologist cannot find his way back, in the record of the great stone book, to the far-off day when life began. The various changes that come over rocks from the action of heat, of water, and of pressure, have slowly modified these ancient beds, so that they no longer preserve the frames of the animals that were buried in them.

These old rocks, which are so changed that we cannot any longer make sure that any animals lived in them, are called the "archæan," which is Greek for ancient. They were probably mud and sand and limestone when first made, but they have been changed to mica schists, gneiss, granite, marble, and other crystalline rocks. When any rock becomes crystalline, the fossils dissolve and disappear, as coins lose their stamp and form when they are melted in the jeweller's gold-pot.

These ancient rocks that lie deepest in the earth are very thick, and must have taken a great time in building; great continents must have been worn down by rain and waves in order to supply the waste out of which they were made. It is tolerably certain that they took as much time during their making as has been required for all the other times since they were formed. During the vast ages of this archæan the life of our earth began to be. We first find many certain evidences of life in the rocks which lie on top of the archæan rock, and are known as the Cambrian and Silurian periods. There we have creatures akin to our corals and crabs and worms, and others that are the distant kindred of the cuttle-

fishes and of our lamp-shells. There were no backboned animals, that is to say, no land mammals, reptiles, or fishes at this stage of the earth's history. It is not likely that there was any land life except of plants and those forms like the lowest ferns, and probably mosses. Nor is it likely that there were any large continents as at the present time, but rather a host of islands lying where the great lands now are, the budding tops of the continents just appearing above the sea.

Although the life of this time was far simpler than at the present day, it had about as great variety as we would find on our present sea-floors. There were as many different species living at the same time on a given surface.

Fig. 94. North America in Cambrian time.

The Cambrian and Silurian time — the time before the coming of the fishes — must have endured for many million years without any great change in the world. Hosts of species lived and died; half a dozen times or more the life of the earth was greatly changed. New species came much like those that had gone before, and only a little gain here and there was perceptible at any time. Still, at the end of the Silurian, the life of the world had climbed some steps higher in structure and in intelligence.

The next set of periods is known as the Devonian. It is marked by the rapid extension of the fishes; for, although the fishes began in the uppermost Silurian, they first became abundant in this time. These, the first strong-jawed tyrants of the sea, came all at once, like a rush of the old Norman pirates into the peaceful seas of Gt. Britain. They made a lively time among the sluggish beings of that olden sea. Creatures that were able to meet feebler enemies were swept away or compelled to undergo great changes, and all the life of the oceans seems to have a spur given to it by these quicker-formed and quicker-willed animals. In this Devonian section of our rocks we have proofs that the lands were extensively covered with forests of low fern trees, and we find the first trace of air-breathing animals in certain insects akin to our dragon-flies. In this stage of the earth's history the fishes grew constantly more plentiful, and the seas had a great abundance of corals and crinoids. Except for the fishes, there were no very great changes in the character of the life from that which existed in the earlier time of the Cambrian and Silurian. The animals are constantly changing, but the general nature of the life remains the same as in the earlier time.

In the Carboniferous or coal-bearing age, we have the second great change in the character of the life on the earth. Of the earlier times, we have preserved only the rocks formed in the seas. But rarely do we find any trace of the land life or even of the life that lived along the shores. In this Carboniferous time, however, we have very extensive sheets of rocks which were formed in swamps in the way shown in the earlier part of this book. They constitute our coal-beds, which, though much worn away by rain and sea, still cover a large part of the land surface.

These beds of coal grew in the air, and, although the swamps where they were formed had very little animal life in them, we find some fossils which tell us that the life of the land was making great progress; there are new insects, including beetles, cockroaches, spiders, and scorpions, and, what is far more important, there are some air-breathing, backboned animals, akin to the salamanders and water-dogs of the present day. These were nearly as large as alligators, and of much the same shape, but they were probably born from the egg in the shape of tadpoles and lived for a time in the water as our young frogs, toads, and sala-

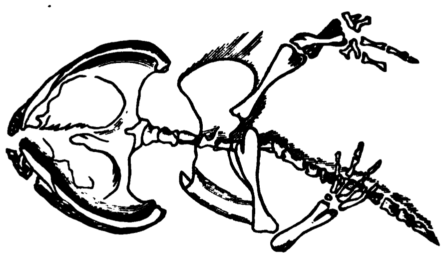


Fig. 95. Raniceps Lyelli — Coal time salamander.

manders do. This is the first step upwards from the fishes to land vertebrates; and we may well be interested in it, for it makes one most important advance in creatures through whose lives our own existence became possible. Still, these ancient woods of the coal period must have had little of the life we now associate with the forests; there were still no birds, no serpents, no true lizards, no suck-giving animals, no flowers, and no fruits. These coal-period forests were sombre wastes of shade, with no sound save those of the wind, the thunder, and the volcano, or of the running streams and the waves on the shores.

In the seas of the Carboniferous time, we notice that the ancient life of the earth is passing away. Many creatures, such as the trilobites, die out, and many other forms such as the crinoids or sea lilies become fewer in kind and of less importance. These marks of decay in the marine life continue into the beds just after the Carboniferous, known as the Permian, which are really the last stages of the coal-bearing period.

When with the changing time we pass to the beds known as the Triassic, which were made just after the close of the Carboniferous time, we find the earth undergoing swift changes in its life. The moist climate and low lands that caused the swamps to grow so rapidly have ceased to be, and in their place we appear to have warm, dry air and higher lands.

Fig. 96. **Cycas circinalis, akin to highest plants of coal time.**

On these lands of the Triassic time the air-breathing life made very rapid advances. The plants are seen to undergo considerable changes. The ferns no longer make up all the forests, but trees more like the pines began to abound, and insects became more plentiful and more varied.

Hitherto the only land back-boned animal was akin to our salamanders. Now we have true lizards in abund-

ance, many of them of large size. Some of them were probably plant-eaters, but most were flesh-eaters; some seem to have been tenants of the early swamps, and some dwelt in the forests.

The creatures related to the salamanders have increased in the variety of their forms to a wonderful extent. We know them best by the tracks which they have left on the mud stones formed on the borders of lakes or the edge of the sea. In some places these footprints are found in amazing numbers and perfection. The best place for them is in the Connecticut Valley, near Turner's Falls,

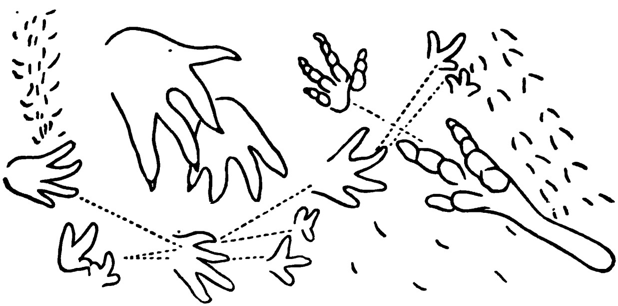


Fig. 97. Foot-prints, Connecticut Sandstones.

Mass. At this point the red sandstone and shale beds, which are composed of thin layers having a total thickness of several hundred feet, are often stamped over by these footprints like the mud of a barnyard. From the little we can determine from these footprints, the creatures seem to have been somewhat related to our frogs, but they generally had tails, and, though provided with four legs, were in the habit of walking on the hind ones alone like the kangaroo. A few of these tracks are shown in the figure on this page.

These strange creatures were of many different species. Some of them must have been six or seven feet high,

for their steps are as much as three feet apart, and seem to imply a creature weighing several hundred pounds. Others were not bigger than robins. Strangely enough, we have never found their bones nor the creatures on which they fed, and but for the formation of a little patch of rocks here and there we should not have had even these footprints to prove to us that such creatures had lived in the Connecticut Valley in this far-off time.

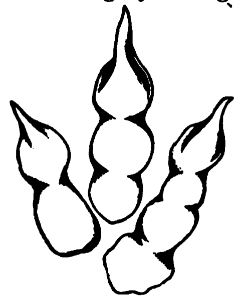


Fig. 98. Foot-print, Turners Falls.

But these wonderful forms are less interesting than two or three little fossil jaw-bones that prove to us that in this Triassic time the earth now bore another animal more akin

Fig. 99.

Dromotherium Sylvestre and Teeth of Microlestes antiquus.

to ourselves, in the shape of a little creature that gave suck to its young. Once more life takes a long upward step in this little opossum-like animal, perhaps the first creature whose young was born alive. These little creatures called *Microlestes* or *Dromatherium*, of which only one or two different but related species have been found in England and in North Carolina, appear to have been in

sect-eaters of about the size and shape of the Australian creature shown in Fig. 100. So far we know it in but few specimens, — altogether only an ounce or two of bones, — but they are very precious monuments of the past.

Fig. 100.
Myrmecobius.

In this Triassic time the climate appears to have been rather dry, for in it we have many extensive deposits of salt formed by the evaporation of closed lakes, of seas, such as are now forming on the bottom of the Dead Sea, and the Great Salt Lake of Utah, and a hundred or more other similar basins of the present day.

In the sea animals of this time we find many changes. Already some of the giant lizard-like animals, which first took shape on the land, are becoming swimming animals.

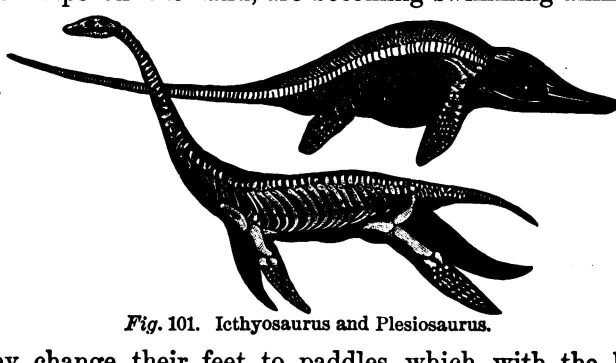


Fig. 101. Icthyosaurus and Plesiosaurus.

They change their feet to paddles, which, with the help of a flattened tail, force them swiftly through the water.

The fishes on which these great swimming lizards preyed are more like the fishes of our present day than

they were before. The trilobites are gone, and of the crinoids only a remnant is left. Most of the corals of the earlier days have disappeared, but the mollusks have not changed more than they did at several different times in the earlier stages of the earth's history.

After the Trias comes a long succession of ages in which the life of the world is steadily advancing to higher and higher planes; but for a long time there is no such startling change as that which came in the passage from the coal series of rocks to the Trias. This long set of periods is known to geologists as the age of reptiles.

Fig. 102. Reptiles of Jurassic Period.

It is well named, for the kindred of the lizards then had the control of the land. There were then none of our large fish to dispute their control, so they shaped themselves to suit all the occupations that could give them a chance for a living. Some remained beasts of prey like our alligators, but grew to larger size; some took to eating the plants, and came to walk on their four legs as our ordinary beasts do, no longer dragging themselves on their bellies as do the lizard and alligator, their lower kindred. Others became flying creatures like our bats, only vastly larger, often with a spread of wing of fifteen or twenty feet. Yet others, even as strangely shaped, dwelt with the sharks in the sea.

In this time of the earth's history we have the first bird-like forms. They were feathered creatures, with bills carrying true teeth, and with strong wings; but they were reptiles in many features, having long, pointed tails such as none of our existing birds have. They show us that the birds are the descendants of reptiles, coming off from them as a branch does from the parent tree. The tortoises began in this series of rocks. At first they are marine or swimming forms, the box-turtles coming later. Here too begin many of the higher insects. Creatures like moths and bees appear, and the forests are enlivened with all the important kinds of insects, though the species were very different from those now living.

In the age of reptiles the plants have made a considerable advance. Palms are plenty; forms akin to our pines and firs abound, and the old flowerless group of ferns begins to shrink in size, and no longer spreads its feathery foliage over all the land as before. Still there were none of our common broad-leaved trees; the world had not yet known the oaks, birches, maples, or any of our hard-wood trees that lose their leaves in autumn; nor were the flowering plants, those with gay blossoms, yet on the earth. The woods and fields were doubtless fresh and green, but they wanted the grace of blossoms, plants, and singing-birds. None of the animals could have had the social qualities or the finer instincts that are so common among animals of the present day. There were probably no social animals like our ants and bees, no merry-singing creatures; probably no forms that went in herds. Life was a dull round of uncared-for birth, cruel self-seeking, and of death. The animals at best were clumsy, poorly-endowed creatures, with hardly more intelligence than our alligators.

The little thread of higher life begun in the Microlestes and Dromatherium, the little insect-eating mammals of the forest, is visible all through this time. It held in its warm blood the powers of the time to come, but it was an insignificant thing among the mighty cold-blooded reptiles of these ancient lands. There are several species of them, but they are all small, and have no chance to make headway against the older masters of the earth.

The Jurassic or first part of the reptilian time shades insensibly into the second part, called the Cretaceous, which immediately follows it. During this period the lands were undergoing perpetual changes; rather deep seas came to cover much of the land surfaces, and there is some reason to believe that the climate of the earth became much colder than it had been, at least in those regions where the great reptiles had flourished. It may be that it is due to a colder climate that we owe the rapid passing away of this gigantic reptilian life of the previous age. The reptiles, being cold-blooded, cannot stand even a moderate winter cold, save when they are so small that they can crawl deep into crevices in the rocks to sleep the winter away, guarded from the cold by the warmth of the earth. At any rate these gigantic animals rapidly ceased to be, so that by the middle of the cretaceous period they were almost all gone, except those that inhabited the sea; and at the end of this time they had shrunk to lizards in size. The birds continue to increase and to become more like those of our day; their tails shrink away, their long bills lose their teeth; they are mostly water-birds of large size, and there are none of our songsters yet; still they are for the first time perfect birds, and no longer half-lizard in their nature.

The greatest change in the plants is found in the com-

ing of the broad-leaved trees belonging to the families of our oaks, maples, etc. Now for the first time our woods take on their aspect of to-day; pines and other cone-bearers mingle with the more varied foliage of nut-bearing or large-seeded trees. Curiously enough, we lose sight of the little mammals of the earlier time. This is probably because there is very little in the way of land animals of this period preserved to us. There are hardly any mines or quarries in the beds of this age to bring these fossils to light. In the most of the other rocks there is more to tempt man to explore them for coal ores or building stones.

In passing from the Cretaceous to the Tertiary, we enter upon the threshold of our modern world. We leave behind all the great wonders of the old world, the gigantic reptiles, the forests of tree ferns, the seas full of ammonites and belemnites, and come among the no less wonderful but more familiar modern forms. We come at once into lands and seas where the back-boned animals are the ruling beings. The reptiles have shrunk to a few low forms, — the small lizards, the crocodiles and alligators, the tortoises and turtles, and, as if to mark more clearly the banishment of this group from their old empire, the serpents, which are peculiarly degraded forms of reptiles which have lost the legs they once had, came to be the commonest reptiles of the earth.

The first mammals that have no pouches now appear. In earlier times, the suck-giving animals all belonged to the group that contains our opossums, kangaroos, etc. These creatures are much lower and feebler than the mammals that have no pouches. Although they have probably been on the earth two or three times as long as the higher mammals, they have never attained any emi-

nent success whatever; they cannot endure cold climates; none of them are fitted for swimming as are the seals and whales, or for flying as the bats, or for burrowing as the moles; they are dull, weak things, which are not able to contend with their stronger, better-organized, higher kindred. They seem not only weak, but unable to fit themselves to many different kinds of existence.

In the lower part of the Tertiary rocks, we find at once a great variety of large beasts that gave suck to their young. It is likely that these creatures had come into existence in a somewhat earlier time in other lands, where we have not been able to study the fossils; for to make their wonderful forms slowly, as we believe them to have been made, would require a very long time. It is probable that during the Cretaceous time, in some land where we have not yet had a chance to study the rocks, these creatures grew to their varied forms, and that in the beginning of the tertiary time, they spread into the regions where we find their bones.

Beginning with the Tertiary time, we find these lower kinsmen of man, through whom man came to be. The mammals were marked by much greater simplicity and likeness to each other than they now have. There were probably no monkeys, no horses, no bulls, no sheep, no goats, no seals, no whales, and no bats. All these animals had many-fingered feet. There were no cloven feet like those of our bulls, and no solid feet as our horses have. Their brains, which by their size give us a general idea of the intelligence of the creature, are small; hence we conclude that these early mammals were less intelligent than those of our day.

It would require volumes to trace the history of the growth of these early mammals, and show how they, step

by step, came to their present higher state. We will take only one of the simplest of these changes, which happens to be also the one which we know best. This is the change that led to the making of our common horses, which seem to have been brought into life on the continent of North America. The most singular thing about our horses is that the feet have but one large toe or finger, the hoof, the hard covering of which is the nail of that extremity. Now it seems hard to turn the weak, five-fingered feet of the animals of the lower tertiary — feet which seem to be better fitted for tree-climbing than anything else — into feet such as we find in the horse. Yet

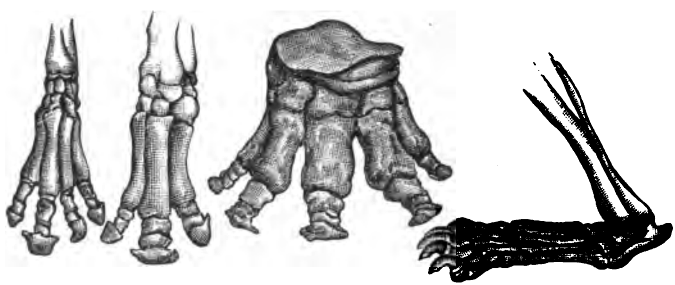


Fig. 103. Feet of Tertiary Mammals.

the change is brought about by easy stages that lead the successive creatures from the weak and loose-jointed foot of the ancient forms to the solid, single-fingered horse's hoof, which is wonderfully well-fitted for carrying a large beast at a swift speed, and is so strong a weapon of defence that an active donkey can kill a lion with a well-delivered kick.

The oldest of these creatures that lead to the horses is called *Eohippus* or beginning horse. This fellow had on the forefeet four large toes, each with a small hoof and a fifth imperfect one, which answered to the thumb. The

hind feet had gone further in the change, for they each had but three toes, each with hoofs, the middle-toed hoof larger and longer than the others. A little later toward our day we find another advance in the *Orohippus*, when the little imperfect thumb has disappeared, and there are only four toes on the forefeet and three on the hind.

Yet later we have the *Mesohippus* or half-way horse. There are still three toes on the hind foot, but one more of the fingers of the forefeet has disappeared. This time it is the little finger that goes, leaving only a small bone to show that its going was by a slow shrinking. The creature now has three little hoofs on each of its feet.

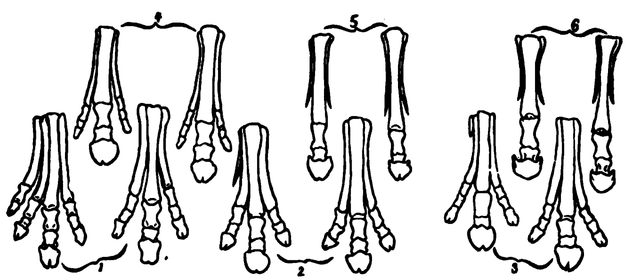


Fig. 104. Development of Horse's Foot.

Still nearer our own time comes the *Miohippus*, which shows the two side hoofs on each foot shrinking up so that they do not touch the ground, but they still bear little hoofs. Lastly, about the time of man's coming on the earth, appears his faithful servant, the horse, in which those little side hoofs have disappeared, leaving only two little "splint" bones to mark the place where these side hoofs belong. Thus, step by step, our horses' feet were built up; while these parts were changing, the other parts of the animals were also slowly altering. They were at first smaller than our horses, — some of them not as large

as an ordinary Newfoundland dog; others as small as foxes.

As if to remind us of his old shape, our horses now and then, but rarely, have, in place of the little splint bones above the hoof, two smaller hoofs, just like the foot of *Miohippus*. Sometimes these are about the size of a silver dollar, on the part that receives the shoe when horses are shod.

In this way, by slow-made changes, the early mammals pass into the higher. Out of one original part are made limbs as different as the feet of the horse, the wing of a bat, the paddle of a whale, and the hand of man. So with all the parts of the body the forms change to meet the different uses to which they are put.

At the end of this long promise, which was written in the very first animals, comes man himself, in form closely akin to the lower animals, but in mind immeasurably apart from them. We can find every part of man's body in a little different shape in the monkeys, but his mind is of a very different quality. While his lower kindred cannot be made to advance in intelligence any more than man himself can grow a horse's foot or a bat's wing, he is constantly going higher and higher in his mental and moral growth.

So far we have found but few traces of man that lead us to suppose that he has been for a long geological time on the earth, yet there is good evidence that he has been here for a hundred thousand years or more. It seems pretty clear that he has changed little in his body in all these thousands of generations. The earliest remains show us a large-brained creature, who used tools and probably had already made a servant of fire, which so admirably aids him in his work.

Besides the development of this wonderful series of animals, that we may call in a certain way our kindred, there have been several other remarkable advances in this Tertiary time, this age of crowning wonders in the earth's history. The birds have gone forward very rapidly; it is likely that there were no songsters at the first part of this period, but these singing birds have developed very rapidly in later times. Among the insects the most remarkable growth is among the ants, the bees, and their kindred. These creatures have very wonderful habits; they combine together for the making of what we may call states, they care for their young, they wage great battles, they keep slaves, they domesticate other insects, and in many ways their acts resemble the doings of man. Coming at about the same time as man, these intellectual insects help to mark this later stage of the earth as the intellectual period in its history. Now for the first time creatures are on the earth which can form societies and help each other in the difficult work of living.

Among the mollusks, the most important change is in the creation of the great, strong swimming squids, the most remarkable creatures of the sea. Some of these have arms that can stretch for fifty feet from tip to tip.

Among the plants, the most important change has been in the growth of flowering plants, which have been constantly becoming more plenty, and the plants which bear fruits have also become more numerous. The broad-leaved trees seem to be constantly gaining on the forests of narrow-leaved cone-bearers, which had in an earlier day replaced the forests of ferns.

In these Tertiary ages, as in the preceding times of the earth, the lands and seas were much changed in their

shape. It seems that in the earlier ages the land had been mostly in the shape of large islands grouped close together where the continents now are. In this time, these islands grew together to form the united lands of Europe, Asia, Africa, Australia, and the twin American continents; so that, as life rose higher, the earth was better fitted for it. Still there were great troubles that it had to undergo. There were at least two different times during the Tertiary age termed glacial periods, times when the ice covered a large part of the northern continents, compelling life of all sorts to abandon great regions, and to find new places in more southern lands. Many kinds of animals and plants seem to have been destroyed in these journeys; but these times of trial, by removing the weaker and less competent creatures, made room for new forms to rise in their places. All advance in nature makes death necessary, and this must come to races as well as to individuals if the life of the world is to go onward and upward.

Looking back into the darkened past, of which we yet know but little compared with what we would like to know, we can see the great armies of living beings led onward from victory to victory toward the higher life of our own time. Each age sees some advance, though death overtakes all its creatures. Those that escape their actual enemies or accident fall a prey to old age: volcanoes, earthquakes, glacial periods, and a host of other violent accidents sweep away the life of wide regions, yet the host moves on under a control that lies beyond the knowledge of science. Man finds himself here as the crowning victory of this long war. For him all this life appears to have striven. In his hands lies the

profit of all its toil and pain. Surely this should make us feel that our duty to all these living things, that have shared in the struggle that has given man his elevation, is great, but above all great is our duty to the powers that have been placed in our bodies and our minds.

APPENDIX.

CRYSTALLINE ROCKS.

OUR rapid glance at the machinery of the world has shown us some little of most of the great engines that are at work within, upon, or without it, — engines that make it the wonderful workshop that it is. Let us now turn back to see some of the lower, but still more important, portions of its mechanism which are given to us in that part of inorganic nature known as the kingdom of crystalline forms.

First, let us notice that nearly all substances in nature have three states of existence: the gaseous, the fluid, and the solid. We are familiar with these three shapes of water because there is only a little difference of temperature needed to carry it through all the stages. Over a fire, a lump of ice will quickly become fluid, and in a short time it will pass into steam, as we are accustomed to term its gaseous state. We do not commonly see this behavior in other substances, because, in iron, for instance, the temperature necessary to carry it from the solid, through the fluid, to the gaseous state, is perhaps thirty or forty times as great as is required to pass water through these stages. It is now believed that all simple substances, such as our metals, and a great many of the more complicated substances, made up by the union of several simple substances, can exist in these three conditions; so that we may accept it as a general truth in nature that

substances have usually the three possible states of solid, fluid, and gas.

While in the state of gas or fluid, all matter seems to remain in a uniform shapeless condition; but when the substance becomes solid, it generally enters into the crystalline form. The best way to get an idea of this peculiar condition is to examine a number of crystalline substances, as, for instance, salt, sugar, alum, quartz, etc. Every day we come in contact with a dozen or more out of the thousands of substances that take this shape.

If we look closely at crystals of one substance, we see that they have the same form, or have shapes that arise from slight changes of a particular form. For instance, crystals of common salt have one shape, while crystals of quartz have a very different shape. The number of sides and the slope of these sides to each other give the peculiar forms.

We do not know what causes different substances to take these different forms, but we do know that from the beginning of the earth each substance has its form, and that they are the same for all time. Further than this, the meteoric stones that fall from the heavens show us that the same rules of form affect the substances in the other planets of our solar system or other solar systems, whence it is supposed that these stones come.

The rules that control the forms of these crystals and make them the subject of the science of crystalography are very interesting, but the matter is too difficult for discussion here. These rules are so precise that this subject is really a branch of geometry as well as a part of chemistry and geology.

We must next notice that if we examine the rocks of the earth's surface, we find that a part of them belong to

the class of stratified deposits, and generally show no signs of crystalline minerals except in cracks which have evidently been filled in by the action of water. Such rocks are generally distinctly bedded, and show us that they have been little changed since they were formed on the bottoms of old seas or lakes.

Then there is another class of rocks, called "crystalline," from the fact that crystals abound all through their masses. These rocks we suppose to have been stratified rocks that have been so much heated that the particles were free to move together as they pleased, and so have gathered into the crystalline form. This heat may have actually melted the rocks, as was the case with some of our granites ; or, the rocks having been made very hot, the water they held in their interstices was able to dissolve the various minerals, and so make them free to take on the shape of crystals. When a mass of limestone is deeply buried in the earth, it becomes heated because it is brought near the hot interior of the earth, and the water that is contained in it dissolves the lime, and so enables the crystals of lime carbonate to form. In this way, our rocks made of limestone mud may be changed to crystalline marble, its different ingredients being gathered together into their several peculiar crystals.

When these stratified rocks, which were once lime stones, mud, sand, and gravel, have their various sub stances changed into crystals, the rocks then become very different from what they were before. The alteration is often so great that we cannot say what the rock was before the change came upon it.

It is from the action of the crystallizing forces on rocks that the most puzzling changes are brought about, and the science of mineralogy comes to exist. The principal un-

crystallized rocks are named from their evident characters, independent of any crystals they may contain. They are made up of various substances, which will be described under their names and with their crystalline forms.

We have already considered these familiar uncrystalline rocks; we will now recall them, and give a statement of the changes that heat and other metamorphic agents may bring to them.

Claystone or Clay Slate. Made of fine mud particles. It may be principally of clay, or partly of lime or quartz. It may contain some carbon, as in the shales near the coals. Useful for building-stones or flagging, etc.; or, when in the shape of true slate, for roofing houses, for which its thin, leaf-like sheets are well fitted. The peculiar structure of roofing-slate is called slaty cleavage, because it is found only in rocks of this description, never in limestones or the coarse-grained rocks. This cleavage is produced in the following way. The slate rock is made up of small bits of many different stones, little fragments of quartz, of feldspar, etc. Among these substances there are generally very numerous, though very small, flakes of mica. These bits of mica are always very thin, generally a dozen or more times as wide as they are thick. When the rock was built in its first form as a soft mud, these flakes fell upon the bottom in many different positions, so that their long faces lie in all sorts of ways. When the rock hardens, they seem to bind it together, somewhat as the hair holds the plasterer's mortar together. Now, if it happens that the rock filled with these mica flakes is very much squeezed, as rocks are when they are forced together by the mountain building forces, it may be forced to stretch itself out in any direction, like dough under the cook's rolling-pin. We can easily see that these several mica

flakes will then all lie in about the same direction. Perhaps this will be more easily seen if we imagine the flakes of mica mingled in dough and then rolled out. The result will be that their longer faces will generally lie parallel with the surface of the flattened cake. It is easy to imagine that when all these flakes are turned by the stretching of the rock, so that their planes are parallel to each other, the rock will split much more easily along the line of their faces than it will across them. It is this adjustment of mica planes that causes our common roofing slate to split so easily into thin sheets.

This slaty cleavage is the simplest of the changes that come over clay stone when it enters into the great laboratory beneath the earth's surface by its burial beneath other rocks. If it is deeply buried, if ten or twenty thousand feet of rocks are laid down upon it, it may undergo very great changes. Thus deeply buried, it becomes very much heated by the inner heat of the earth. This affords the particles of the rock a chance to become dissolved in water and rearranged in the crystalline form. This gives us a mica schist, or other similar rock, in place of the original slate. If still further heated, so that the rock melts, the mass may become a trap-like rock, and lose all trace of its original structure and character.

Limestones and Limestone Marbles. When limestones are subjected to the action of heated water, the rock becomes more solid, the fossils are dissolved away, and the whole mass takes on a more or less crystalline form. These crystals are generally of lime carbonate, but sometimes of lime sulphate or gypsum, or other salts of lime. In this changed form, limestone affords the greater part of the polished stone used in building and for table-tops, etc.

Sandstones. Heat and heated water work to change

sandstones into more compact rocks, termed "quartzites." In these rocks we can no longer see the distinct grains of sand, but the whole is converted into a rather solid mass of flinty matter. The grains of sand are taken to pieces in the heated water and re-made so that the crystals are all close set and locked together.

In these changes of claystones, limestones, and sandstones, the alteration is so slight that the mass is still distinctly a bedded rock. But the changes may go still further. The rocks may be so kneaded together by the strong movements that take place in the depths of the earth that the bedding which so distinctly marked the water origin of the material can no longer be traced. It also happens that other chemical substances, besides those originally in the rock, are gradually brought in by the percolating waters, so that the chemical nature, as well as the shape, of the mass is changed. It is probably in this way that a host of rocks, which are termed "gneisses," "granites," and "syenites," are formed. In some cases we can still trace a remnant of the bedding of these greatly changed rocks, enough to show that they were originally made on sea-floors as stratified deposits.

If the heat or the action of heated water still further affect the rocks, they may take on either of two other shapes. They may be converted into dykes or into veins.

Dykes are formed when the rock is so heated that it more or less completely melts. In this melting, it is aided by the water that all rocks contain. In this melted state, it is squeezed into crevices of other rocks, as before described. This trap matter is generally highly crystallized, and, of course, has lost all trace of its stratification.

Veins are deposits of matter nearly always in the crystallized form, where the carriage of the matter into a

crevice has been brought about by the action of water, which first dissolves the substances, and then allows them to deposit as crystals. In the several ways above described, a great variety of crystals is formed, and from the association together of different crystals a great many rocks are made.

Of these crystals, which altogether amount to several hundred species or kinds, the following are the most important and the most common in rocks.

1. *Quartz*, by far the commonest crystals found on the earth. Almost all sand consists of broken crystals of this substance. Its usual form is that of a six-sided prism, with a six-sided pyramid at the end. Sometimes there is a pyramid at each end. It also, but very rarely, crystallizes six-sided tables. Ordinarily, these crystals are transparent and glass-like, but they may be colored of many tints, as of a violet or amethyst color. They are always too hard to be scratched by steel. Quartz is very often found in the uncrystallized form, as in flint, agate, chalcedony, etc.

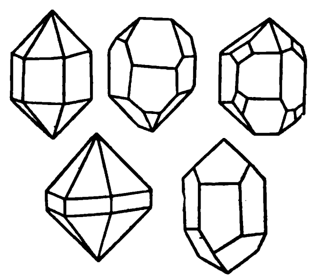


Fig. 105. Quartz, common forms.

2. *Feldspar*. This is, next after quartz, the commonest crystal in the rocks. It is about as heavy and as hard as quartz,—about two and one-half times the weight of water. Its crystals split in two directions, breaking easily into parallelograms, with smooth, waxy-looking, lustrous sides, while quartz crystals do not split in this fashion. The crystals vary so much in form that they cannot be represented here.

3. *Mica.* This is a very common crystal, which easily splits in thin, elastic flakes. Sometimes the crystals are as transparent as glass, but more commonly they are yellow, wine-colored, green, or smoky in hue. Commonly, the crystals are small, as in granites, but when occurring in veins they are sometimes a foot or more across. Flakes from these large crystals are used for stove windows, for covering photographs, or for the battle lanterns and windows of our ships, where glass would be broken by the jar of guns or of the enemies' shot. This substance may easily be distinguished from all others by the fact that undecayed crystals will always yield elastic flakes when divided with the knife. The thin flakes broken from mica crystals are very buoyant and float far in the water. They may be seen glistening in most sandstones.

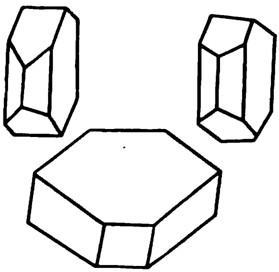


Fig. 106. Mica.

Hornblende. Next after the three above named, one of the commonest minerals is hornblende. It is very variable in all its qualities. It may take the shape of oblong prisms, of tufts, of crystals, or of hair-like fibres laid close together. Sometimes these fibres are so long and elastic that they may be spun and woven like cotton. In this shape, the mineral is termed "asbestos," which means *unburnable.* This name has been applied to it because it

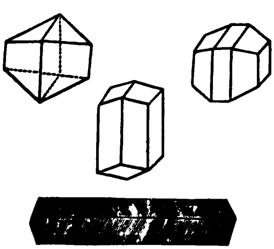


Fig. 107.
Hornblende, common forms.

has been used in making a cloth which is quite fireproof. Among the ancients, such cloth was sometimes used to wrap the dead on the funeral pyre, so that the ashes of the consumed body might not be scattered.

This mineral is composed of the elements silica, lime, magnesia, and iron.

Pyroxene is closely akin to hornblende in composition, but the crystals have the form shown in the figure. It is never fibrous, nor does it show the brush-like crystals common in the latter mineral.

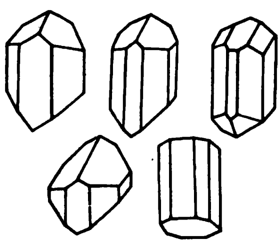


Fig. 108. Pyroxene.

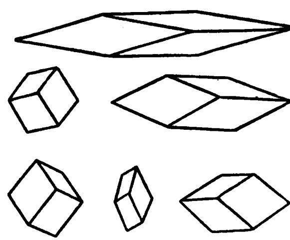


Fig. 109. Calcite.

Calcite. This is one of the commonest minerals. It is the shape taken by ordinary limestone or lime carbonate when crystallized. The crystals have the form shown in the diagrams. They are soft, and easily scratched with a knife. It may be of several different colors, and is often transparent. It is composed of 44 parts of carbonic acid and 56 of lime.

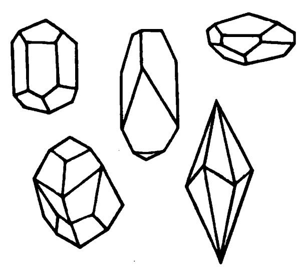


Fig. 110. Dolomite.

Dolomite is akin to calcite, from which it differs in having carbonate of magnesia

along with carbonate of lime. It is much less abundant than calcite. The forms of the crystals are shown in the figures.

An easy test for these minerals is made by dipping them in a powdered shape into muriatic acid diluted with one-half its bulk of cold water. Calcite will cause the mixture to foam or effervesce freely at once, while it will be necessary to heat the acid and water before the dolomite will give off its gas, except in a very sparing way.

Gypsum is a very common mineral. It is a combination of sulphuric acid and lime with water. When burnt, it is the plaster of paris of the arts, much used in making casts of statues and various fine mouldings. It occurs in two forms. In one, it is combined with some water, when it crystallizes in the shape shown by Fig. 111. In the other, it is without any water in its combination, when it takes a rectangular shape.

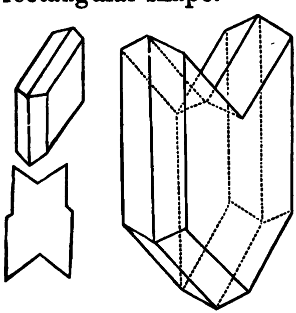


Fig. 111. Gypsum.

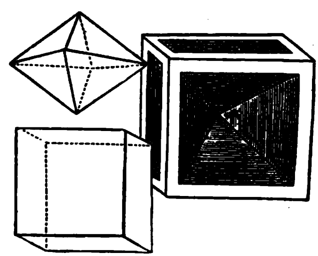


Fig. 112. Common Salt.

Common Salt. This is a compound of sodium and chlorine. Its crystals have the form shown in the figures. It often makes beds hundreds of feet in thickness. In this form, it is generally of a brownish color, and only partly transparent; but sometimes this rock salt is as transparent as ice. It is formed wherever salt water is enclosed in a

basin, where it receives so little rain water that it evaporates. It is then thrown down in crystals on the bottom. Salt is now depositing in many shallow, land-locked pools along those portions of the seashore that have little rain, and also in many inland seas that have no outlet, as, for instance, in the Salt Lake of Utah, the Dead Sea of Asia, etc. There were certain periods in the past history of the earth when salt was very extensively deposited. They were probably the times of least rainfall.

The foregoing are the commonest crystalline minerals of the rocks. There are others, which, though less frequently found, are still common, and should be recognized by the student. First among these, we may notice certain ores of the important metals. It will be noticed that all of them are not found in the form of crystals.

Pyrite, or *Pyrites*, is composed of sulphur and iron. It commonly has a light yellow hue, which causes it to be often mistaken for gold, whence it receives the popular name of "fools' gold." Its crystals are shaped as in Fig. 113. These crystals, when exposed to the air, quickly take up oxygen, and rust or burn sometimes with such rapidity that they give an intense heat. As they often occur in large quantity in coal, their burning frequently fires coal-mines or ships laden with the coal. Hundreds of ships have been lost in this way. By allowing these crystals to burn, sulphuric acid may be produced.

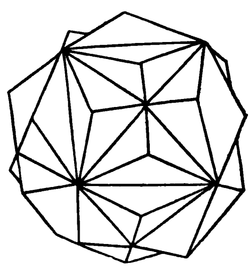


Fig. 113. Pyrite.

Magnetite. This is a crystalline ore of iron, occurring in the shapes shown in the figure. It is of a grayish or

blackish color. The peculiarity which distinguishes it from other minerals, is that the crystals strongly attract the magnetic needle. This mineral occurs both in beds and in veins. It is as yet not known what causes the magnetic character. It may be due to the action of heat. A large part of the iron now in use is derived from magnetite.

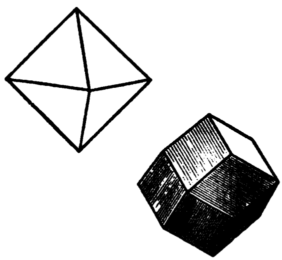


Fig. 114. Magnetite.

Hematite, so named from its blood-red color, is sometimes found in crystals, but more often in the massive form. It generally occurs in beds. It stains the hand red, and is hence frequently called "dye-stone ore." This ore is often fossiliferous, the fossil shells, etc., having been converted into the iron oxide. It is composed of two parts of iron to three of oxygen.

Limonite is much like the preceding, except that it does not occur in crystals, and is of a brownish or yellowish color. It may be formed by the combination of water with the hematite ore.

Hematite and limonite are often found together as distinctly bedded iron ores. They represent the little-changed iron ores that are often found interbedded in our limestones, sandstones, and slates.

Siderite, or *Iron Carbonate*, is a combination of carbonic acid and iron, and is made by the infiltration of iron oxide into limestone beds, which takes away a part of the lime, replacing it with iron. It readily decays, so that while it at first is of a bluish or whitish color, and looks like limestone, on exposure to the air it soon becomes a limonite, or, in some cases, a hematite. It is generally in

massive, stratified form; but, when crystallized, it takes the shapes shown in the figures.

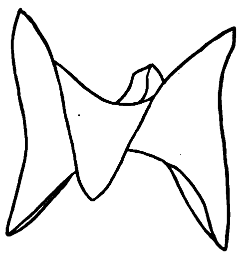


Fig. 115. Siderite.

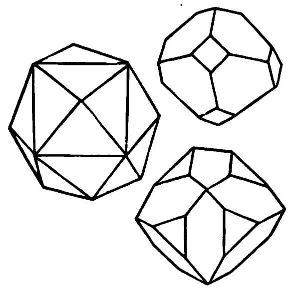


Fig. 116. Metallic Copper.

Ores of Copper. Copper is often found as a pure metal, scattered through various rocks in the form of grains or sheets. Especially is it abundant in this form on the southern shore of Lake Superior. In its metallic state, it is sometimes crystalline, as in the forms shown in the figures. More commonly, it occurs as ore, of which the following is the most important, viz.:—

Copper Pyrites, or *Chalcopyrite*, composed of sulphur and iron, with a variable proportion of copper. It is closely related to iron pyrites, and differs from it by the presence of copper.

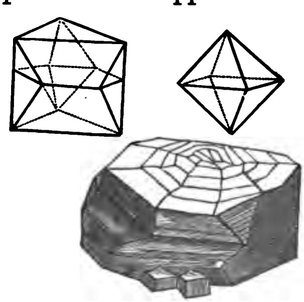


Fig. 117. Galena.

There are many other ores of copper formed by its mixture with other metals, but the principal production of copper is from the two forms above given.

Lead. This substance is never found in the metallic state. Its principal ore is galena, or lead sulphate. It has the color of lead when

the crystals are fresh. It contains 13 per cent of sulphur. It always occurs in crystals that have the form given in the figure. It is commonly found in veins, but sometimes in beds, where the galena has been gathered in the shape of obscure veins. The crystals have the shape shown in the figure. They are easily split along the sides of the crystals.

Lead generally contains more or less silver, and a large part of the silver of the world is extracted from galena.

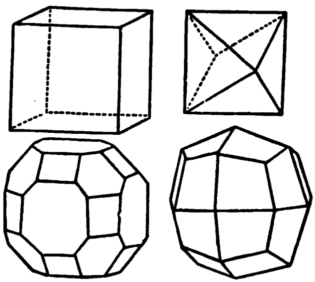


Fig. 118. Silver.

Silver occurs in the form of various oxides, but sometimes it is found in the metallic form as threads or sheets running through the rock. When crystallized, its crystals have the form shown in the figure. The principal ores of silver are formed by combinations with sulphur, bromine, chlorine, but its commonest form of occurrence is in mixture with galena or with copper ores.

Zinc. This metal is, like lead, not naturally found in the metallic state. Its common form of occurrence is in the shape of sphalerite or zinc blende, a combination of 33 parts of sulphur and 67 of zinc. The crystals are of various colors, from yellow to black. When powdered, they give a white dust. The crystalline forms are shown in the figures. This metal is frequently associated with lead in ordinary veins or veinlets in bedded rocks.

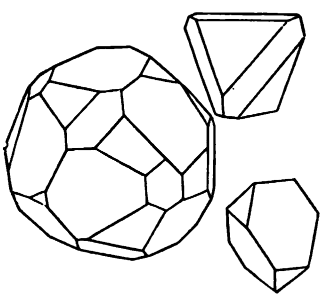


Fig. 119. Sphalerite.

Tin. This is one of the rarest metals in America, being the only one of the important metals that has never been profitably mined in this country. It is generally found in the shape of thin veins in granite rocks. Its only important form is that of cassiterite or tin oxide, in which shape

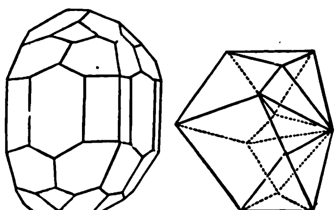


Fig. 120. Cassiterite.

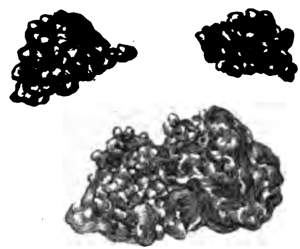


Fig. 121. Stream or Nugget Gold.

it is a dark-brownish, very heavy, ore. The crystals are found in the shapes shown in the figure. These crystals do not easily dissolve; so, when the rock wears away, they often are gathered in the river-beds like gold and platinum, and are called "stream tin." The most of the tin of commerce has been collected in this way.

Gold. This metal is, with the possible exception of platinum, the metal that is least disposed to combine with other substances. It is therefore generally found in the metallic state, usually in the form of grains, sheets, or fibres in the rocks or in the sands of rivers. Though the most sparingly accumulated in masses of all metals, it is

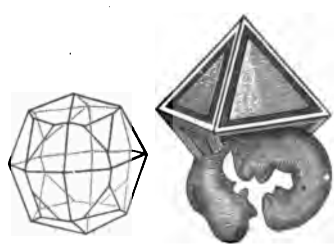


Fig. 122. Crystals of Gold.

perhaps the most generally disseminated of all. The most

of our clays and sands contain traces of it. In its crystalline shapes, which it rarely assumes, it has the forms shown in the figure.

Aluminum. This metal is never found in the metallic state, though it is perhaps the most plentiful of all the metals that could be used by man in his arts. In its ordinary form, it exists as a compound of alumina and silic oxide, and is a most important element in all our common clays. This metal is of a silvery-white color; it is wonderfully light, being scarcely heavier than heavy wood, and remarkably strong. But for the fact that it is exceedingly costly to reduce it to the form of a metal, it would be perhaps, after iron, the most important of all to man.

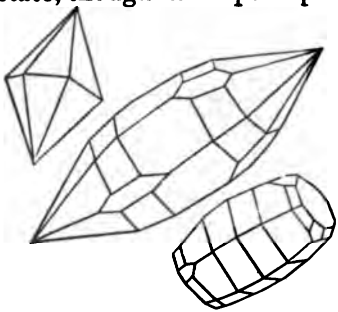


Fig. 123. Corundum.

Sulphur. This substance plays a large part in the geological world. It is rarely found in the crystalline form,

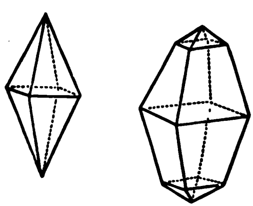


Fig. 124. Sulphur.

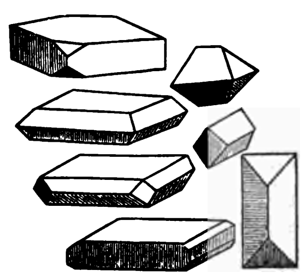


Fig. 125. Baryta.

except in the neighborhood of volcanoes. The crystals have the well-known resinous-looking yellow color. They have the shapes shown in the figures.

There are several other less important crystals that may be mentioned. Among these barytes, or heavy spar, a compound of sulphuric acid and baryta, is the heaviest of the crystals after those of metallic substances. It has the form shown in Fig. 125. Fluorite, or fluor-spar, a compound of fluorine and calcium, is one of the handsomest of our crystals. Its colors range from white to blue or yellow. See Fig. 126. Arrogonite, a form of lime carbonate, gives crystals shown in Fig. 127.

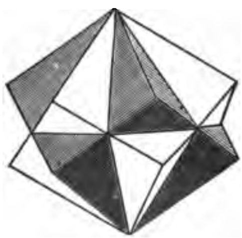


Fig. 126. Fluorite.

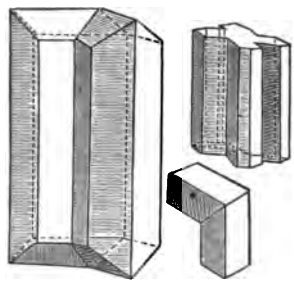


Fig. 127. Arrogonite.

When certain of the foregoing crystals are associated together in a mass of rock, the rock receives particular names, according to the crystalline substances that enter into its composition. Of these rocks, named from the crystals they contain, the following are the most important.

Granite, composed of intermingled crystals of quartz, feldspar, and mica, irregularly crowded together. The proportion of the several sorts of crystals may vary, as well as the forms of the crystals themselves.

Syenite is a name given to rock composed, like granite, in part of quartz and feldspar crystals, but having some form of hornblende crystals in place of mica.

Gneiss. When the rock has the crystals crowded to-

gether in a banded form, the rock is called "a gneiss." In some cases, this banded arrangement is the remains of stratification planes that once marked the rock in a distinct way as a water-made deposit. If the mica crystals are present, it is called a "granitic gneiss"; if the hornblende crystals are present, it is called a "syenitic gneiss."

Mica Schist. When the mica plates are very abundant, and the feldspar less considerable, the rock becomes very easily splitable, and shines all over from the reflection of the mica plates. It is then called a "mica schist." When the hornblende is abundant, it is called a "hornblende schist."

Porphyry. This is a name given to any rock when there is a cementing mass of feldspar or quartz in which distinct crystals of feldspar, or feldspar and quartz, are lodged. There are very many kinds, and, as most of them are handsome when polished, they have been much used for decorative stones.

The following-named rocks are not crystalline. They are found in association with the crystalline rocks, and deserve the attention of the beginner in geology.

Steatite, or *Soapstone*, a rock largely composed of magnesia, generally of a mottled, greenish-white color, thick bedded or entirely massive. It has a curious soapy feel. Much used in making stoves, fire-backs, and in other places where heat must be endured.

Serpentine. Also largely composed of magnesia, and much resembling soapstone, except it feels less soapy. Like soapstone, it is easily cut with the saw. It is more mottled than soapstone, takes a good polish, is generally of a beautiful greenish color, and hence is much used for decorative purposes.

Quartzite. This is a sandstone that has had its grains more closely cemented together than in ordinary sandstones. Sometimes the grains are so blended that they are no longer visible. In this shape, it is often called "chert," or "flint." Sometimes, by changes which we do not understand, the quartzite becomes flexible, so that a slender piece can be bent in the hand. It is then called Itacolumite, from a mountain in Brazil, where it was first found. It occurs plentifully in North and South Carolina.

There are many hundred forms of crystals, and some score of rocks, composed in larger or smaller part of these crystals, which are not mentioned here, for the reason that they are not of common occurrence on the earth's surface.[1] The most important of these omissions is the series of volcanic rocks. These are, it is generally believed, the ordinary stratified rocks, that have been completely melted and driven up to the surface. Their variations are due in part to the original chemical nature of the rocks, and in part to the way in which they have cooled from their melted state.

In general, we may say that the crystalline rocks represent those portions of the earth's crust which have been the most changed by heat, acting directly or through hot water, that penetrates the rocks. When the crystalline rocks wear down, their crystals are generally broken to pieces, and go to make mudstones, sandstones, or limestones, to be again gathered into crystals when they are deeply buried in the earth's crust, and so exposed to the action of heat.

[1] For further information concerning crystals, see Professor J. D. Dana's *System of Mineralogy*, 5th edition, New York, 1873; also his *Manual of Geology*, New York, 1880, from which, in part, this brief account is taken.

Thus we see that the rocks, and the minerals found in them, revolve in an eternal circle by the action of water. They are constantly changing into the condition of mud. When they have long been buried in the crust of the earth, they become changed to the crystalline structure. Their change to this condition is largely the effect of water action. As the lands wear down, the rocks once again pass into the control of water, and are returned to the sea-floor.

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